Quantitative Risk Assessment and Evolution Trajectory of China’s Iron Ore Resource

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Abstract. The resource security system is a complex system. Strategic mineral resource is of great importance to national security and economic development. Iron ore is one of the 24 strategic mineral resource determined by the Chinese government. Based on the broad connotation of resource security, we put forward the risk assessment model of resource security named 3E (Enduring, Economic, Environmental) model and establish a complete risk assessment index system for iron ore. In this paper, the entropy method is used to determine the weight of each index, we evaluate the comprehensive risk of iron ore from 2000 to 2016, and analyse the results of risk assessment in detail. The results show that the supply risk is on the rise, which has the greatest impact on the comprehensive risk. Moreover, the fluctuation of economic risk is more stable, and the environmental risk is decreasing. The comprehensive risk index of China’s iron ore increased firstly and then declined. From 2000 to 2007, it was a relatively low-risk period; from 2008 to 2010, the risk was increased; 2011-2013 was a high-risk period; and 2014 to 2016, there was a reduction in risk. In order to effectively control the risk of iron ore, this paper puts forward some suggestions from several aspects.

1. Introduction
Resource security is an important part of the national security system. Strategic mineral resource is an important guarantee for the development of national economic security, national defence security and strategic emerging industries. With the exploitation of mineral resource, the ecological and environmental problems are getting more and more concern. Thus, the connotation of mineral resource security has gradually expanded to supply security, economic security and ecological environmental security [1-5]. As the most important strategic mineral, iron ore plays a basic role in steel and many downstream industries [6], and has always been the object of competition and control targets of all countries in the world [7].

Due to high-intensity development, problems such as resource depletion and environmental damage are becoming more and more serious, and mineral resource security has always been a research hotspot in the field of national security [8]. In the research content, it mainly focuses on the evaluation and comparison of different varieties of mineral resource security [5], the difference analysis of mineral resource security on different spatial scales [9-10], and the evolution trend of mineral resource security status [11]. In terms of research methods, the indicator system method is the most commonly used for resource security evaluation by domestic and foreign institutions and scholars [12-16]. Yang used fuzzy comprehensive evaluation method to evaluate the risk of iron ore...
import from the perspectives of import source, import market, transportation channel, emergency reserve, import management, capital and non-product market competition [17]. Fan et al. also used fuzzy comprehensive evaluation methods to evaluate the supply risk of iron ore from five aspects: market risk, resource risk, political risk, market power, and future supply and demand trends [18]. Liu et al. used the entropy weight method to establish an indicator system from four dimensions: resource, environment, industry and market to evaluate the safety status of iron ore in China [19]. Limited by the difficulty of obtaining complete and accurate data, the research on the quantitative evaluation of mineral resource security is less and the accuracy is not very high.

Based on the general connotation of resource security, this paper establishes a comprehensive evaluation index system for iron ore resource security risk, and obtains complete data of various indicators during the period from 2000 to 2016 from national government departments. Then, this paper uses the entropy method to determine the weights of different indexes, and quantitatively evaluates iron ore resource security risk, and finally analyse the evolution of risk based on the calculation results, and propose reasonable risk management and control recommendations.

2. Quantitative Assessment Method for Resource Security Risk

2.1. Evaluation Model Construction
Strategic mineral resource security mainly covers three aspects: supply security, economic security and ecological security [20]. This paper proposes the 3E evaluation model: “Enduring, Economic, and Environmental” for mineral resource security. “Enduring” refers to the stable and continuous supply of mineral raw materials and is a core element of resource security. “Economic” is mainly reflected in the consumption and price of mineral resource. “Environmental” refers to the sense of conservation and environmental friendliness in the development and utilization of mineral resource.

2.2. Establishment of Indicator System
The establishment of the indicator system is the basis for resource security risk assessment. In the development of evaluation indicators, this paper focuses on the integrity and accessibility of the data sources of indicators based on the analysis of various influencing factors. The architecture of indicator system is shown in figure 1.

![Figure 1. Architecture of indicator system.](image)

Based on the lots of analysis, this paper constructs a resource security risk assessment index system of the iron ore with three first-level indicators, seven second-level indicators and twelve third-level indicators, as shown in table 1. A comprehensive risk index should be set to describe the overall situation of national iron ore risk within a certain period of time, namely the comprehensive risk index of iron ore resource security, which is obtained by weighted integration of three levels of indicators.
Table 1. Resource security risk assessment index system of iron ore.

| First-level | Second-level | Third-level | Data sources |
|-------------|--------------|-------------|--------------|
| A1 Enduring | B1 Endowment | C1 Reserve-production ratio | a, b |
|             | B2 Domestic supply | C2 Self-sufficiency rate | b |
|             | C3 Recycling of secondary resource | c, d |
|             | C4 Import intensity | b, d |
|             | C5 External dependency | b |
|             | C6 Import concentration | b |
|             | C7 Import capacity for overseas import | e, f |
| A2 Economic risk | B4 Resource consumption | C8 Consumption intensity | a, b |
|             | C9 Per capita consumption | a, b |
|             | C10 Import price | b |
| A3 Environmental risk | B7 Energy consumption | C11 Energy consumption per ton of iron | a, b |
|             | B7 Level of environmental governance | C12 Total investment in environmental pollution control | a, b |

Notes: a National Bureau of Statistics, b <China Mining Yearbook>, c <Report on the Development of China’s Renewable Resources Recycling Industry>, d World steel association, e Tata database, f Customs Information of China.

3. Iron Ore Resource Security Risk Analysis

3.1. Enduring Analysis

According to the latest USGS statistics [21], the global iron ore reserves are mainly distributed in Australia, Russia, Brazil, China and other countries. Since the average grade of iron ore in China is only about 30%, the reserves of raw ore account for 12% of the world’s total reserves, while the reserves of iron only account for 9% of the world (figure 2). The supply and demand pattern of the global iron ore industry is basically stable. The demands are mainly in China, Japan, the European Union [22]. China’s iron ore mining intensity is large; the reserve-production ratio is about 15 years, far lower than the world’s 80-year average [23].

Since 2000, China’s iron ore imports have declined slightly except in 2010, and other years have been increasing (see figure 3). The sharp increase in iron ore imports in China has caused an increase in world iron ore prices and freight rates, which in turn has an impact on domestic supply. In terms of domestic supply, iron ore production in 2000-2014 increased rapidly and peaked in 2014 (see figure 3). Since 2015, iron ore prices have plummeted, producers have cut production, and iron ore production has declined. From 2000 to 2016, China’s iron ore production increased by an average of 13% per year, while iron ore imports grew at an average annual rate of 19.5% over the same period, imports growth is more rapid (figure 3).

In terms of demand, China’s iron ore exports are small, and the apparent demand is approximately equal to the sum of domestic production and imports (figure 4). Since 2003, with the advancement of China’s industrialization and urbanization, China’s iron ore demand has grown rapidly, reaching its peak in 2014, and then the demand growth rate has gradually decreased. This indicates that industrialization has entered the middle and late stages [24]. It is expected that with the decline in iron ore demand and the increase in secondary resource supply, the future shortage situation of iron ore resource in China is expected to be alleviated [18].
Overseas resource supply is related to the stable acquisition of a country’s resource and is a major source of risk [14]. Since 2003, China has become the world’s largest importer of iron ore, with imports accounting for more than 50% of total global imports (see figure 5: import strength). The data shows that China’s self-produced iron ore has been in short supply for a long time. Since 2014, due to the sharp drop in international iron ore prices, domestic mines have suffered losses and continued to reduce production, and the external dependency of iron ore is more than 80% (see figure 4: external dependency), far higher than the internationally recognized 50% warning line, the potential risk of the imbalance of iron ore supply gradually accumulate and expand. At the same time, the distribution and production of iron ore resource in the world is highly concentrated, and the “import concentration degree” of iron ore in China has also remained high, mainly from Australia, Brazil, South Africa, India, etc. The sum of imports from the top three importing countries accounts for about 80% of the total imports (see figure 5: import concentration), which has a great political risk.

3.2. Economic Analysis
To evaluate the economic rationality of iron ore resource utilization, consumption intensity and per capita consumption should be considered. Figure 6 shows the changes in these two indicators. The iron ore consumption intensity reflects the amount of iron ore resource consumed per unit of GDP, and the per capita consumption describes the iron ore consumption level of each national. Although the overall consumption intensity shows a downward trend, the utilization efficiency of iron ore is increasing, but the per capita consumption is increasing. This shows that even if China's economic growth slows down, per capita iron ore consumption remains at a high level, and the risk of iron ore resource consumption is slowly rising and tending to be flat.
China’s iron ore import sources are relatively concentrated, and the bargaining power in the international iron ore market is weak. In the face of the violent fluctuations in international trade prices, China’s ability to resist risk is very fragile. Between 2000 and 2016, China’s iron ore import prices experienced several significant fluctuations, and the overall price rose first and then decreased (see figure 7). In 2009, affected by the financial crisis, prices plummeted. In recent years, the price of iron ore has been falling, resulting in many high-cost iron ore enterprises in China losing, reducing production and even exiting the market [25], which has led to an increase in external dependency and further, accumulation of risk.

### 3.3. Environmental Analysis

The government and the society have paid more and more attention to environmental issues, and gradually increased the investment in environmental pollution control. The quality of China’s ecological environment has continued to improve, and the overall trend has been stable. In addition, the energy consumption during the iron ore mining process has gradually decreased since 2005, and environmental damage and pollution caused by mining and selection have been controlled. Changes in both environmental governance and energy consumption are beneficial to ecological environment protection (figure 8), and environmental risk are reduced.

### 4. Quantitative Risk Assessment and Results Analysis

#### 4.1. Risk Assessment Result

According to the iron ore resource risk assessment index system, indicator data can be obtained by transforming all the original data into an equation. According to the entropy method weighting step, processed the data, and the weights of the iron ore resource security risk can be obtained. Multiply the
indicator data by the corresponding weights, the integrated risk index is obtained. According to the risk calculation results, the evolution trajectory of China’s iron ore resource security risk index is shown in figure 9.

![Figure 9. Risk index value of iron ore resource from 2000 to 2016.](image)

### 4.2. Comprehensive Risk Analysis

It can be seen from figure 8 that the iron ore resource comprehensive risk index experienced the evolution process of rising and then falling back mainly due to the enduring risk. The enduring of iron ore is generally on the rise, mainly related to the increase in import intensity, demand and external dependency, and the self-sufficiency rate and the ratio of reserve to production are gradually decreasing. Import concentration has remained high, and political risk are high too. The interaction between consumption intensity, per capita consumption and import price has reached a relatively balanced state, so the economic risk is relatively stable. As China’s environmental protection concept has gradually increased, policy guidance is conducive to environmental friendliness, and environmental risk are gradually reduced.

After calculation, the lower limit of China’s iron ore resource comprehensive risk index is 50.43 (2002), and the upper limit is 71.57 (2013). According to this, the classification standard of iron ore comprehensive risk index is set: 70-100 is high risk, 60-70 is medium high risk, 50-60 is medium low risk and 0-50 is low risk. According to this risk grading standard, 2000-2016 can be divided into four stages: 2000-2007 is medium low risk period; 2008-2010 and 2014-2016 are the medium high-risk period; 2011-2013 is the high-risk period; 2011-2013 is the high-risk period.

In the low-risk period, the risk of reserve-production ratio, import intensity, external dependency, per capita consumption, and iron ore import price are all small, and the enduring and economic risk are also low, but it is slowly rising over time. In addition, the environmental risk during this period is at a high level and is gradually decreasing. In the medium high-risk period of 2008-2010, especially after the 2008 financial crisis, both the enduring and economic risk increased, the environmental risk decreased slightly, and the comprehensive risk showed a rapid rise. In the high-risk period, the risk values of the 12 indicators in the previous years were generally large, and the comprehensive risk index was close to or exceeded 70, which was at a high-risk level, and the comprehensive risk reached a peak in 2013. In the medium high-risk period from 2014 to 2016, the comprehensive risk index decreased rapidly in 2014-2015, but there was an upward trend in 2016. The performance was high in iron ore port inventory, and the imbalance between supply and demand risks was not optimistic.

### 5. Conclusion

This paper adopts the comprehensive evaluation method of multi-index system based on “3E” model, uses the entropy method to determine the objective weight of each index, comprehensively evaluates
the security risk of iron ore resource and analyzes the risk evolution law of long-term scale, which provides a reliable basis for quantitative assessment and risk management of iron ore resource security risk and also provides a methodology for risk assessment of other similar strategic mineral resource.

China’s iron ore resource is of rich reserve and low grade. In present years, the demand has reached its peak, but it will remain high in the short term, resulting in a situation of short supply, relying heavily on imports. This paper calculates the “enduring risk”, “economic risk”, “environmental risk” and comprehensive risk index for each year from 2000 to 2016. The calculation results and related analysis show that, due to factors such as increasing import intensity, demand and external dependency, self-sufficiency rate and reserve-production ratio, the enduring risk generally show an upward trend and have the greatest impact on comprehensive risk. Economic risk fluctuations are less affected by the interaction and automatic adjustment of factors such as consumption intensity, per capita consumption and import price. Environmental risk is declining due to the increasing annual investment in environmental governance and the reduction in energy consumption intensity. In the time evolution of the comprehensive risk index, from 2000 to 2016, the iron ore resource comprehensive security risk index first increased and then decreased, 2000-2007 was the medium low risk period; 2008-2010 and 2014-2016 were the medium high-risk period; 2011-2013 is a high-risk period. The comprehensive risk quantitative calculation results are consistent with the actual situation. The evaluation systems and methods are comparable and comprehensive, and can be applied to other strategic mineral resource.

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