Effect Evaluation and Policy Research on the Exploitation Management of Rare Earth Resources

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Abstract

Rare earth elements are considered as strategic nonrenewable resources. Thus, enormous attention has been paid to the exploitation management by the government and industry. Policy interventions can have a certain effect on the supply and market of rare earth. The purpose of this study is to evaluate the impact of China's rare earth policy. We assessed the exploitation management during 1998–2018. Based on the national strategies and policy objective, the process of policy evolution was categorized into three stages. Then, we used an empirical model to examine the effect of policies at different stages, from which it was found that strengthened resource exploitation management effectively controlled mining and production, while influencing international trade and price. Under the mining restrictions, a sharp decline in rare earth resources can be evaded, which could ensure the sustainable supply capacity of rare earth resources. Furthermore, the consolidation of policy, along with resource management, would facilitate China to effectively regulate its supply and set the prices to an extent.

Keywords: *The rare earth elements, resources exploitation, management policy, empirical model, effect evaluation*

I. Introduction

The rare earth elements (REEs) are regarded as crucial strategic resources owing to their applications in new energy materials, electronic information technology, and nuclear industry [1,2]. With the advancement of the application value of REEs in the global socioeconomic development, the global consumption of rare earth resources would continue to grow. A report from the US Geological Survey claimed that at the end of 2017, there were approximately 130 million tons of REEs reserves (rare earth oxides [REOs]) globally, 80% of which were located in China, Brazil, Vietnam, and Russia [3]. At present, China is the world's largest producer, user, and exporter of REEs, providing 62% of global rare earth ore production in 2019 (Fig 1); however, China's reserves are accounted for only about 30% [4].

Although China's REEs supply makes a significant contribution to the international market, demand expansion has led to several issues, including resource exhaustion, environmental pollution, illegal exploitation, and smuggling. Thus, China had implemented comprehensive measures in the links of mining, production, circulation, and export of rare earth goods to protect both the resources and environment [5,6]. Currently, China has brought strategic resource management under law. After the integration of rare earth mining areas, the government and industry are collaborating to regulate ore mining and eliminate backward production capacity. Moreover, environmental monitoring would be reinforced.

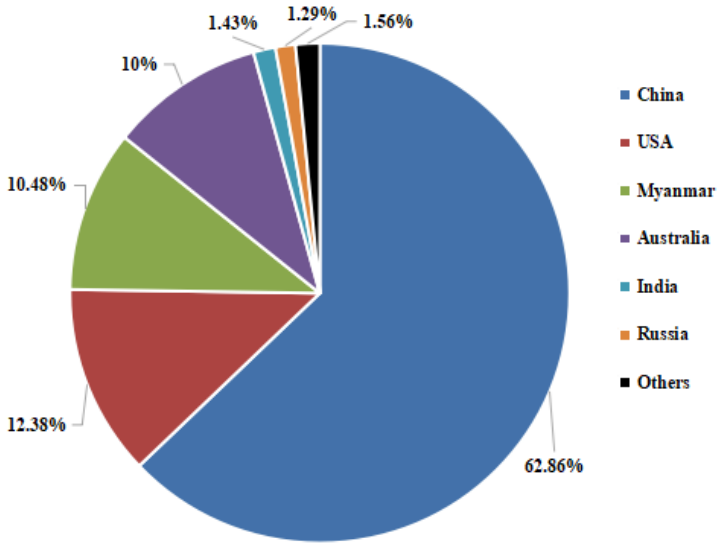

Fig 1: Distribution of global REEs production in 2019

The current literature on REEs policy primarily focuses on export trade and REEs supply. To date, many studies have investigated export controls and their impact on global supply and market price [6–12]. On the one hand, some studies reported that the policy of China on REEs would markedly affect the RE market. In addition, restriction policies issued by the Chinese government would not only increase its pricing power but also reverse the paradox of the "large country effect" to a certain extent [13]. Zhang et al. claimed that Chinese export policies have exerted a significant impact and suggested that focus could shift from controlling exports to controlling production [14]. On the other hand, some scholars expressed different views. Sun examined the micro trade data and found through empirical methods that the market power of China RE exports was relatively weak [15]. Zhu reported that China lacked market power in the international REEs trade export market [16].

In 2014, China canceled the export restriction policy, which led to the research of supply trends to become a hot topic around the world [17]. Indeed, some studies explored the supply situation of China and its impact on the industrial chain [18–20]. To secure a stable supply of REEs, Chinese policies focus on the resource protection [21]. In addition, studies have made a supply forecast of Chinese REEs and proposed some policy implications. Wang et al. estimated the production of the three significant REEs in China before 2050 based on the generalized WENG model [22]. Ge et al. predicted the production of China's REOs would increase by 10.8%–12.6% in 2025. From the policy perspective, national policy guidance is also an important factor restricting its supply [23].

As rare earth resources became strategic global reserve resources, numerous researchers have shown interest in investigating sustainable development. Some scholars focused on domestic policy of resource management. For example, resource conservation [24,25], environmental regulation [26,27], resources tax [28], and recycling measures [29,30]. The studies mentioned above on industry policy contributed to a comprehensive analysis of the political actors and domestic narratives. Besides, several studies explored the sustainability evaluation based on the financial perspective, resource governance, recycling, and potentials for substitution [31–33].

Despite Chinese REEs policy receiving considerable attention, limited empirical studies have discussed the impact of policies. Moreover, not much literature is available on the impact of mining management policy assessed using quantitative methods. Thus, this study estimates the impact of REEs policy from the perspective of the policy evolution process. By analyzing the strategic adjustment of national policy, this study contends that Chinese REEs policy has undergone three stages of development. Furthermore, an evaluation model is constructed to explore the policy effect at different stages. Finally, it offers policy implications based on the conclusion of this study.

II. Analysis of Exploitation Management Policy

2.1 Process of policy evolution

Before the 1990s, China was a small producer and an exporter of low-value rare earth concentrates [24,34]; thus, the state began controlling the development and production of rare earth resources. From 2000 onwards, China became the world's leading producer and exporter [35], as well as moved from a laggard position to a dominant position [36]. In this situation, the government focused more on the advantageous mineral resources. Indeed, numerous rare earth policies were successively implemented in China since 1998. In this study, we divided the major exploitation management policies into three stages, as shown in Fig 2.

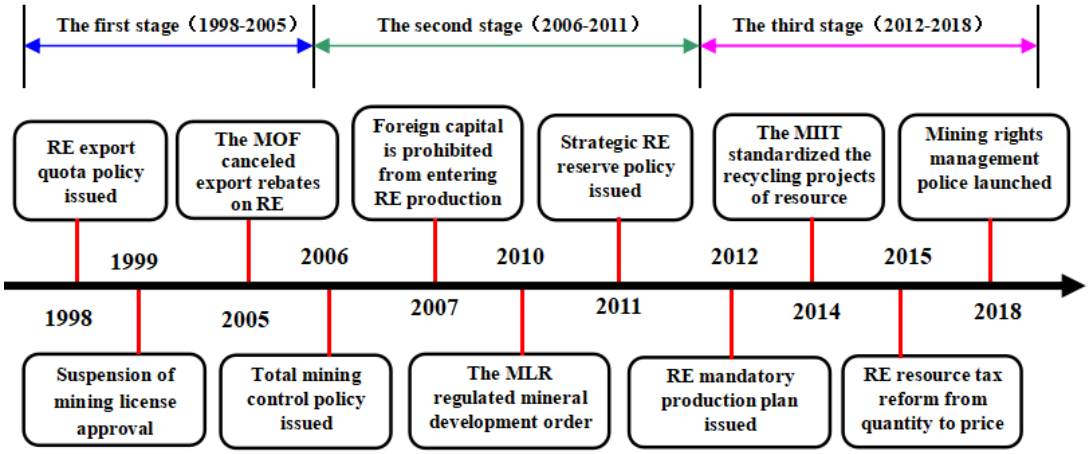

Fig 2: Exploitation management policies in China from 1998 to 2018

2.1.1 The first stage (1998–2005)

With the rapid development of global semiconductor industry, the demand of rare earth at home and abroad has been growing rapidly. Large amount of capital entering the rare earth mining and smelting leaded to blind expansion of industrial scale. As a result, Chinese rare earth reserves decreased from 43 million tons to 27 million tons during 1995–2002. Due to the disorderly expansion and the illegal behavior of rare earth exploration and mining, the problems of resource waste and environmental pollution has been increasing.

As the main management direction in the first stage, the government took mining license and export quota. The production and export quantity of REEs were regulated by restrictive mining policies, which were targeted to protect strategic mineral resources and limit the export of REEs including rare earth raw materials and rough processed products. Besides, the government also strives to address the problems of ecological environment damage of domestic rare earth industry by curtailing over-exploitation and illegal mining; these measures started from the upstream of rare earth industry to plan management and protection of resources.

2.1.2 The second stage (2006–2011)

Chinese export of rare earth occupies a dominant position in the international market. However, the low added value of products and the lack of pricing power make the export price deviate from the value of rare earth itself. China realized the unsustainability of the development model of "exchange resources for foreign exchange". Consequently, China executed some policies to regulate export quantity management, mining and total production from 2006.

In the second stage, China continued regulating measures on exploiting rare earth resources. The total mining amount control is the leading management direction. The original Ministry of Land and Resources allocated the total amount control index of rare earth mining to provincial authorities since 2006. Meanwhile, the government

began rectifying the order of mineral development and prohibited foreign capital from entering the rare earth industry. The policy aimed to decrease the intensity of rare earth resources development and enhance the efficiency of resource utilization. Since 2011, the State Material Reserve Bureau of China planned to implement the rare earth strategic reserve policy to ensure the sustainable supply of rare earth resources, which targeted domestic companies to rationally use rare earth resources.

2.1.3 The third stage (2012–2018)

In the third stage, great changes have taken place in international situation. On one hand, The United States, Japan and the European Union filed a trade lawsuit for China's violation of the WTO agreement in 2012. After the lawsuit in 2015, China was forced to cancel the quantity management measures of rare earth export. On the other hand, China's global share of rare earth reserves and production decreased with the discovery and exploitation of new rare earth mines abroad. Therefore, the global rare earth market entered a diversified supply pattern.

Since 2012, the Ministry of Industry and Information Technology formulated the Interim Measures for the management of mandatory production plan of rare earth resources. The qualified production enterprises should apply for the plan to the provincial industrial competent department. After the assessment organized by the Ministry of Industry and Information Technology, the production plan is issued in two batches each year. Thus, in the third stage, mandatory production plan management is the main management measure, which exerts a certain impact on the supply side of the rare earth market. The introduction of these policies aimed at standardizing the rare earth production and operation activities.

2.2 Realistic observation of policy influence

During this period, China has implemented several policies that had a profound impact on the development of the rare earth industry. This study intuitively judges the impact degree of policy by comparing the change of index before and after the policy implementation.

2.2.1 Mining amount of rare earth

China began setting rare earths exploitation control index policy in 2006. The rare earths exploitation control index, which is based on the State Council's “Notice on the Restructuring and Standardization of Mineral Exploitation,” promulgated in 2005. Rare earths exploitation control index have been increasing year by year. Fig. 3 shows the variation track of the rare earth mining volume during 2006-2018.

Comparing the mining control index with the output revealed that the impact effect gradually appears. As the control index failed to produce sufficient binding force on mining enterprises, the output still exceeded the control index in the second stage. China reinforced the supervision on the implementation of the total mining control index, thereby resulting in a significant decline during 2010–2011. Moreover, the mining control index increased because of the increased market demand during 2012–2018. Since 2013, the output of the rare earth mine and the control index has reached the same level. Furthermore, the implementation of the policies in the third stage exerted a certain impact on the output.

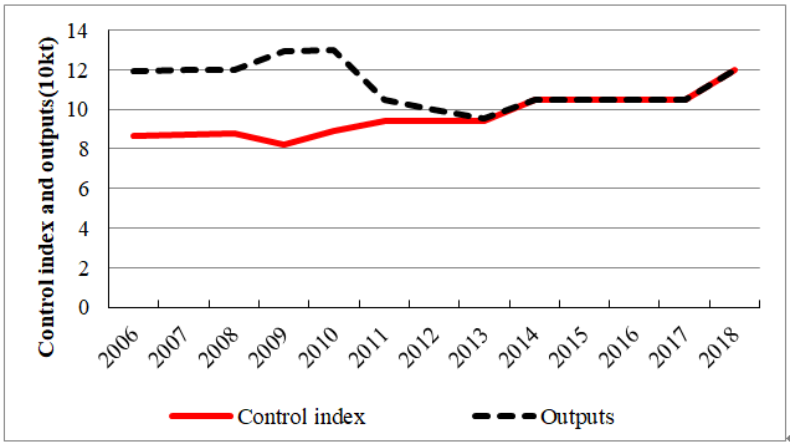

Fig 3: Control index and mining output of REEs

2.2.2 Two types of rare earth mineral products

In China, there exist different resource conditions and distribution patterns of rare earth resources. While the light rare earth resources primarily comprise mixed-type rare earth deposits in Inner Mongolia and Shangdong, Sichuan Provinces, the medium and heavy rare earth resources are mostly ionic-type rare earth deposits in Jiangxi, Guangdong, Fujian, and other southern provinces [37]. Of note, the state has separately issued mandatory production plans for the process of producing rare earths products. The Ministry of Industry and Information Technology (MIIT) began to set quotas for minerals, smelting and separation products differentiated between light rare earths and heavy rare earths.

To reflect the control effect, changes in the output and index of two types of rare earth minerals in China during 2006–2018 are shown in Fig 4. The trend of light rare earth production and mining index are similar. Notably, the output of medium and heavy rare earth products has far exceeded the mining index before 2010. With the gradual evolution of the policy, it has been lower than the mining index since 2011, and the output has completely reached the target level in recent 3 years, which shows that the policy exerts a greater impact on the control of medium and heavy rare earth resources, which completely reflects the strategic position in China.

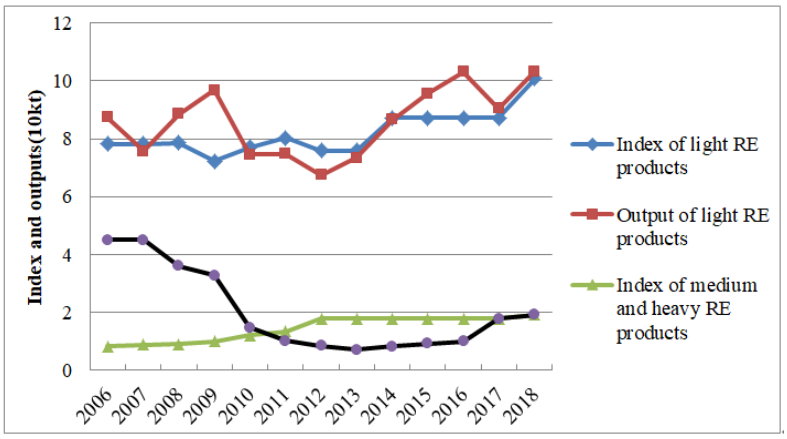

Fig 4: Mining index and output of two types of rare earth mineral products

2.2.3 Imports and exports

Recent years have witnessed an increased consumption of rare earth resources, thereby affecting the growth of China's domestic demand [38]. China's import in rare earth raw materials increased from 2054 tons in 2001 to a peak of 96,601 tons in 2018 (Fig 5). The import of rare earth raw materials has markedly alleviated the scarcity of domestic rare earth mineral products. To ensure the sustainable development of the rare earth industry and fulfill

the actual consumer demand, the import volume of rare earth raw materials started increasing significantly after 2015. Considering the strategic protection of Chinese rare earth resources, it is anticipated that the imported minerals would become a crucial source of rare earth minerals for Chinese rare earth enterprises in the future.

On the export side, the volume remained at approximately 60,000 tons before 2008. The data revealed that the export volume of rare earth materials from China has been gradually declining, along with an increase in the average price since 2008. Rare earth crisis burst in 2011, and the sharp decline in rare earth supply made the availability and reliability of supply more ambiguous [25]. To sustain economic growth, the export volume has returned to a stable state in recent years.

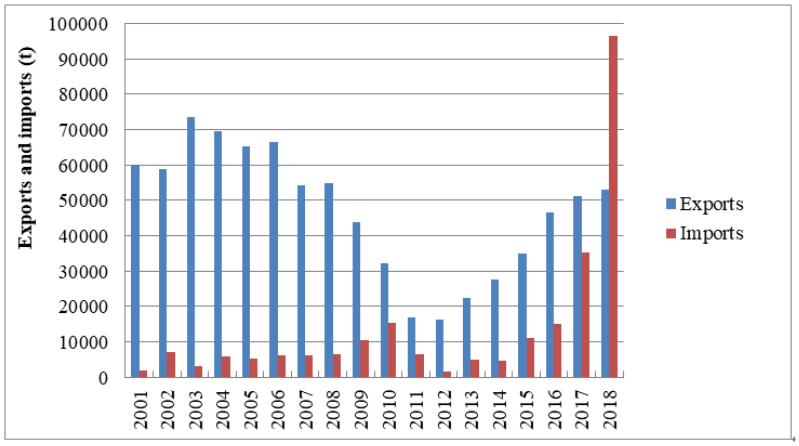

Fig 5: China's imports and exports of rare earth from 2001 to 2018

2.2.4 Price of rare earth export products

Figure 6 and 7 show the export volumes and unit price of China's REEs from 2001 to 2018. The data were extracted from the UN COMTRADE database and includes two commodity groups classified as rare earth metals (HS280530) and REOs (HS284690). The unit price is calculated by dividing the total amount of export trade by the volume of export. Following a period of low value during 2001–2005, the average prices of two products increased from 2006 to 2010, and reached a peak in 2011; this response correlated with Chinese industrial policies, including those on REEs mining and processing, export quota, and value-added duties [39]. With the gradual progress of export volume, the price is in a stable development state in recent years.

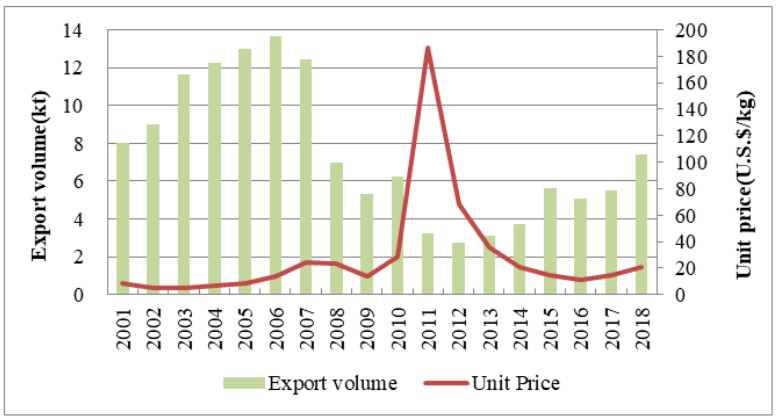

Fig 6: Exports volume and unit price of rare earth metals (HS280530)

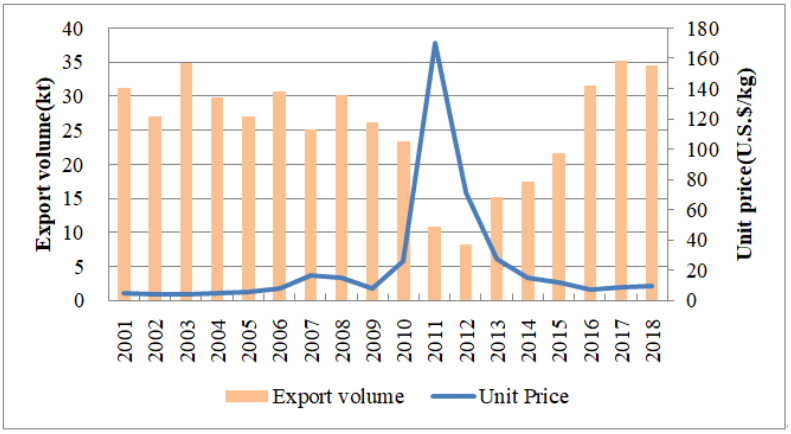

Fig 7: Exports volume and unit price of rare earth oxides (HS284690)

III. Constructing Policy Effect Evaluation Model

3.1 Evaluating indicator

Considering the impact of the mining control policy, we selected four evaluation indicators as dependent variables. In particular, the mining amount of rare earth presents the annual production of rare earth mines in terms of REOs. The recoverable period (measured by the ratio of recoverable reserves to current production) captures resource sustainability. The data were collected from the US Geological Survey. In addition, the output of mineral products (annual production of rare earth minerals in terms of REO) was included in the model, and the related data were attained from the CBC metal network. The average price of export (measured by the ratio of trade value to exports volume) reflects the price impact in the world market, and the related data were obtained from the UN COMTRADE database. The indicators cover the annual data during 1998–2018. Table 1 shows the descriptive statistics.

Table 1 Descriptive statistics (1998–2018)

Indicator	Definition	Unit	Number of samples	Mean	Std. dev.	Max.	Min.
Mining amount of rare earth	MIAM	10,000 tons	21	9.72	2.29	13.00	5.33
Recoverable period	REPE	year	21	455.00	179.31	807.00	225.00
Output of mineral products	OUTP	10,000 tons	21	9.34	2.53	13.25	5.20
Average price of export	AVPR	US $ per kg	21	18.25	34.63	168.56	3.27

3.2 Empirical model

In this study, we took the effect evaluation indicators as the dependent variable and established the Multiple Regression Model. To distinguish the impact of different stages of policy, the virtual variable of the critical index was set up. The specific settings of the measurement model are as follows:

$$y_t = c + \alpha_1 t + \alpha_2 (t - t^*) D_n + \varepsilon \quad (1)$$

$$D_n = \begin{cases} 1 & t > t^* \\ 0 & t \le t^* \end{cases} \quad (2)$$

Where y_t denotes the evaluation indicators of the policy effect; c implies a constant; t indicates the year; α_1 and α_2 are the parameters to be estimated; ε denotes the random disturbance term; and D_n is the virtual variable of the industrial policy. We took time and industrial policy dummy variables as explanatory variables for the effect of the rare earth policy in different stages. Considering the lag of policy implementation, it set 2006 and 2012 as the critical values of virtual variables. Of note, D_1 denotes the virtual variable of policy for the second stage, which captures the period after 2006, and D_2 captures the period after 2012, which signifies the third stage.

The model and data presented above were used to test the policy effect of the exploitation management policy in China. Natural logarithm was taken for each evaluation indicators in the measurement process. Then, we used the least square method for regression analysis. To reflect the positive impact of the policy, it must attain a statistically significant coefficient.

IV. Results and Discussion

Table 2 shows the results of measurement and analysis. After adjustment, R^2 was >0.8, suggesting that the explanatory power of the equation was strong. In addition, the impact of policies was significant on the indicators. The economic analysis results are as follows:

Table 2 Regression results of policy effect evaluation model

Variable	LnMIAM	LnREPR	LnOUTP	LnAVPR
c	−172.497***(12.576)	3.040***(0.037)	1.444***(0.056)	−158.22*(58.763)
t	0.087***(0.006)	−0.068***(0.005)	0.104***(0.008)	0.079**(0.029)
$(t-t^*)D_1$ (t*=2006)	−0.117***(0.015)	0.146***(0.012)	−0.186***(0.018)	0.185**(0.071)
$(t-t^*)D_2$ (t*=2012)	0.038*(0.020)	−0.107***(0.016)	0.154***(0.024)	−0.628***(0.114)
Adjusted R^2	0.932	0.907	0.919	0.820
F-statistic	86.149***	61.797***	71.905***	25.857***
Durbin–Watson	1.481	1.623	1.393	1.179

Note: *, * *, and * * *are respectively significant at the level of P < 0.1, P < 0.05, and P < 0.01, and the standard errors of regression coefficient are in ( ).

4.1 The mining amount of rare earth has been effectively regulated

The first stage of industrial policy did not limit the production and export of rare earth resources, resulting in the mining volume of rare earth increasing at an average annual rate of 8.7% during 1998–2005. In the second stage, the total mining control policy decreased the growth rate to –3.0% (0.087–0.117). As the market demand for rare earth is growing, the total amount control index of mining in the third stage increased as well. Moreover, the average annual growth rate of output reached 0.8% (0.038–0.030). Overall, the resource management policy exerted a positive impact on the rare earth production control since 2006.

4.2 Rare earth resources have been developed rationally

Owing to the swift growth of mining volume and limited reserves, the recoverable period reduced year after year at the rate of 6.8% in the first stage. Nevertheless, the indicator of the recoverable period increased by 7.8% (0.146−0.068) in the second stage. In the third stage, the recoverable period reduced by 2.9% (0.078−0.107) with the increase of yield. The findings suggested that the implementation of the mining management policy evaded the disorderly mining of rare earth and ensured the sustainable supply capacity of rare earth resources.

4.3 The excessive production of enterprises has been curbed effectively

In the first stage, the output of rare earth mineral products increased at an average annual rate of 10.4%; however, it began declining at an average annual rate of 8.2% (0.104−0.186) in the second stage, which suggested that the situation of overproduction in rare earth enterprises has been controlled. In the third stage, the output of rare earth minerals increased at a rate of 7.2% (0.154−0.082). Furthermore, the implementation of the mandatory production planning policy caused the production of enterprises to match the market demand more closely.

4.4 The price of the average export tends to be normal

Chinese rare earth industry developed swiftly in the 1990s [6], while disorderly price competition among domestic enterprises caused the prices of rare earth resources to fall linearly. As the export volume of REEs continues to increase, the average export price of REEs has been in a downturn until 2005. The implementation of the mining management policy affected the exports volume and price indirectly. The average price exhibited a notable upward trend in the second stage. Compared with that before 2006, the average price growth rate reached 10.6% (0.185−0.079). In the third stage, the export trade tended to be stable, and the change in export price was also influenced by the development of the new material industry and market regulation. Furthermore, the average export price index was significantly affected by the policy, especially in the second and third stages ($P < 0.05$).

V. Conclusion

This study analyzed the exploitation management policies of China's rare earth resources and the effects on the REEs market supply by using an effect evaluation model. As the management policy of rare earth resources has reformed in different periods, we divided the policy evolution during 1998−2018 into three stages. In addition, we investigated the effects on mining amount of REEs, two types of rare earth mineral outputs, and price of rare earth exports. Moreover, we used an empirical model to evaluate the impact of three different stages. Thus, we reached some conclusions as follows:

From 1998 onwards, China has introduced many exploitation management policies related to rare earth resources. During this period, the evolution of policy experienced three stages, and policies issued at each stage were formulated per the strategic objectives. From mining license and export quota to the total exploitation and production control management, the policies exerted a profound impact on the development of the rare earth industry.

Under the mining restrictions, a sharp decline in rare earth resources was avoided, which improved the level of effective resource utilization. Export prices are primarily dependent and volatile on Chinese policy measures. Since 2006, the relevant policies have affected the average export price of rare earth resources. Of note, an adjustment in import policy as a way to ensure sustained and effective supply of mineral resources and achieve the goal of strategic reserve.

The government has strengthened the planning management of rare earth mining, which would continue to constrict the supply of REEs to keep the prices high. The consolidation of policy, together with the resource management, would facilitate China to utilize resources effectively and enhance product value, which have been made to maintain the development of the rare earth industry sustainable and healthy.

Accordingly, we propose the following policy recommendations. Based on the issuing control targets, effective supervision measures should be taken to curb illegal mining and production beyond or without targets. In addition, consolidating the classification management of rare earth resources and establishing a long-term mechanism of the strategic reserve could enhance the economic value of REEs resources. Besides production control measures, other incentive policies might attain the policy objective of recycling and comprehensive utilization of rare earth resources [40]. For example, financial subsidies should be proposed and implemented to boost the firms to make high value-added REEs products through technology innovation [41]. Only if the Chinese government maintains policy continuity can the exploitation and production be sustainable.

Acknowledgements

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