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ENVIRONMENTAL REGULATION, ENVIRONMENTAL POLICY COMPLEXITY AND TECHNOLOGICAL INNOVATION EFFICIENCY

Abstract: Previous studies on the relationship between environmental regulation (ER) and technological innovation efficiency of defence industry (TIE-DI) mainly focus on variability and complexity, while few empirical studies have incorporated environmental flexibility into models, and most of them are based on questionnaires. Therefore, this paper takes environmental regulation and environmental policy complexity (EPC) as the entry point, so as to discuss the feasibility of improving the technological innovation efficiency of China's defence industry enterprises (CDI), which aims to empirically test the mechanism of ER and EPC on improving the efficiency of applied technological innovation of China's defence industry enterprises. The research conclusion provides sufficient theoretical basis and empirical support for strengthening the technical innovation efficiency support, standardising the market order and the market leading, establishing the information disclosure mechanism and improving the internal control of industrial enterprises.

Keywords: environmental regulation, environmental policy complexity, technological innovation efficiency, sustainable development

Introduction

In the "14th Five-Year Plan", the relevant departments proposed to "strive to achieve the carbon peak in 2030 and 2060", which once again highlights the strategic significance of green development. The implementation plan of carbon peak before 2030 issued on October 26, 2021 points out: at present, China has entered the key time point of implementing the Five-Year Plan. By 2025, China's CO_2 emission per unit of Gross Domestic Product (GDP) will decrease by about 30 % compared with that in 2020, in which natural gas consumption accounts for more than half to meet the national emission reduction requirements, and the CO_2 emission intensity is controlled within a reasonable range. At the end of 2020, the sixth meeting of the Central Committee for comprehensively deepening reform also clearly put forward the idea that emphasising the need to promote the formation of a strong domestic market. As one of the largest developing countries in the world, China's energy rigid demand will continue to grow in the future with the continuous improvement of China's industrialisation and urbanisation level. Carbon peaking is the basis and premise of achieving high-quality development, while CO_2 emission is an important way to achieve low-carbon transformation.

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Under the condition of market economy, CDI (China's defence industry enterprises) are facing serious environmental pollution problems, which put forward higher requirements for them. In order to remain invincible in the competition, CDI must improve the technological innovation efficiency, change the backward production mode, and improve the production efficiency and market competitiveness. Therefore, it is one of the important measures to realise the transformation of economic mode and green development to study the environmental policy and technical problems faced by CDI. Moreover, to improve their resource utilisation rate, and build a technical innovation efficiency system is suitable for China's national conditions. Technological innovation efficiency, environmental policy and innovation performance are the main external environmental factors affecting CDI. Therefore, to study the impact and mechanism of ER (environmental regulation) on technological innovation is helpful to promote their transformation and upgrading. At present, there are few research results on the effect of ER.

Based on the above background, this study extends ER from environmental variability to environmental flexibility to explore the mechanism of ER on Technological Innovation Efficiency of Defence Industry (TIE-DI), and further investigates the regulatory effect of EPC (environmental policy complexity) on the relationship between ER and TIE-DI. Moreover, it is significant to expand the scope of green industrial policy research for China's government. Previous studies on ER mainly focus on variability and complexity, while few empirical studies on environmental flexibility are included in the model, and most of them are based on questionnaires. In view of this, based on the dual dimensions of environmental variability and complexity, this paper integrates ER into quantitative research, and discusses how that affects the TIE-DI, innovation motivation and environmental flexibility of CDI.

Literature review

The impact of ER on the TIE-DI

At present, there are two different views on the impact of ER on the TIE-DI: one is that ER hinders the TIE-DI. External risk averse will demand a higher risk premium or not investment behaviour, which makes CDI more difficult to finance. As a result, there is not enough capital to support them to continue to innovate. Miao et al. [2] believed that environmental variability, namely environmental volatility and unpredictability, as one of the performance of ER, represents frequent market volatility. It is difficult for CDI to accurately estimate the surplus, which may reduce the market value, and ultimately affect the TIE-DI.

Another point of view shows that ER faced by CDI will promote the green innovation in order to seek new development direction. Based on the growth option theory, Shen et al. [3] found that TIE-DI is accompanied by the characteristics of high income and high risk. If CDI succeed in innovation and increase the number of green patents authorised, it is equivalent to setting entry barriers in disguise, which can effectively prevent peers from entering and occupying the market. Zhang and Wang [4] believed that when CDI are faced with the uncertain factor of market competition, if they can produce products that cannot be imitated or surpassed by the competitors in the same industry through the TIE-DI, the gap can be widened, the competitiveness can be enhanced, and thus occupy a larger market. On the contrary, Zhou and Wang [5] found that if CDI do not carry out the TIE-DI, they may be seized by other competitors, resulting in huge losses. Yuan and Xiang [6] divided

ER into environmental variability and environmental flexibility. Based on theoretical and empirical analysis, this paper examines the impact of ER on innovation intensity, and concludes that only the performance of environmental change significantly stimulates the TIE-DI, while the promotion effect of environmental flexibility is not obvious [7].

Zhang and Liu [8] believed that there was an uncertain and more complex nonlinear relationship between ER and TIE-DI, that is, the inverted "U" relationship, which means that in a certain range, the strengthening of ER can promote the TIE-DI, but beyond a certain extent, it will produce the opposite effect.

The impact of EPC on the TIE-DI

The relationship between EPC and TIE-DI can be traced back to "Porter Hypothesis". According to that, Qiao et al. [9] concluded that proper ER can actually improve competitiveness. According to Zhang and Wang [4] they thought ER will not make CDI lose their competitive advantages over competitors. Asiedu et al. [10] insisted that the mandatory of EPC gives CDI few choices, that is, they have to bear more environmental protection costs and reduce the profits. Therefore, the author finds that if EPC can eventually produce economic benefits, the business entities pursuing profit maximisation will not give up this profitable opportunity. The Porter hypothesis, based on the dynamic perspective, believes that the appropriate EPC has a positive impact on technological innovation. Although there will be temporary cost crowding.

Based on the two component theories of Porter hypothesis, scholars have summarised the relationship between EPC and innovation from three aspects. Pukhova et al. [11] pointed out from a dynamic perspective that the environmental policies will increase the cost of CDI in a period of time. However, if the perspective is long-term, the appropriate EPC will stimulate the TIE-DI and reduce the cost. On the one hand, EPC is lagging behind, and may lead to more pollution, which is manifested as industrial modernisation and economic development process slowing down at the macro level. On the other hand, the inhibitory effect of EPC on the TIE-DI is also reflected in the production and sales links, such as setting obstacles to the production of products.

Through industry heterogeneity, Yi et al. [12] put forward different views on the relationship between EPC and the efficiency of technological innovation. By selecting industries as samples, it is found that there is a nonlinear "U-shaped" relationship between the two. Based on the complexity characteristics of environmental policies, Feng et al. [13] and others confirmed that under the dual threshold of command and control, the positive nonlinear relationship between EPC and green productivity is more significant. Generally speaking, changes in market conditions will generally change the competition conditions or strategies between the regulated entities and the government, which may change the win-win or constraint relationship between EPC and TIE-DI.

Analysis and review

Through the review of the relevant research above, we can see that the research on ER, EPC and TIE-DI are relatively rich, but there are also shortcomings: (1) in the research on the relationship between ER and TIE-DI, the definition of ER is single, such as only from the perspective of environmental flexibility and variability, not measured by multi dimensions, the research perspective can be further broadened. (2) "Porter Hypothesis" has not reached a consistent conclusion on the relationship between the EPC and TIE-DI, but there is no doubt that EPC will affect the TIE-DI. (3) There is still plenty of literature on

ER, EPC and TIE-DI, and there is no relatively complete research system. Therefore, the relationship between the three is still a focus of environmental economics research, which needs further discussion. in the long run, EPC can promote the rational use of resources, and give consideration to the improvement of ecological protection and production efficiency. It can make up for or even exceed the cost effect, and finally get the "win-win" result of TIE-DI.

Table 1

Variable definition table

Type	Name	Symbol	Definition and calculation method
Explained variable	Technological innovation efficiency of enterprises in China’s defence industry	lnTIECDI	Natural logarithm of the sum of green invention patents and green utility model patents
Explanatory variables	Environmental regulation of China’s defence industry	ERDIE	The interaction between environmental flexibility and variability
	Environmental flexibility of China’s defence industry	EFE	The main business income as the index of the Herfindahl index, and negative processing
	Environmental variability of China’s defence industry	ECE	Industry adjusted sales revenue volatility
Adjustment variable	The complexity of environmental policies for China’s defence industry	CEPE	The comprehensive intensity of policy accounting through the method of complexity
Control variable	Scale of China’s defence industry	SCDI	Natural logarithm of total assets of national defence industrial enterprises
	Enterprise value of China’s national defence industry	CDIEV	The proportion of the sum of market value of owner’s equity and liabilities in total book assets
	Asset liability ratio of China’s defence industry	Lev	Total liabilities / assets at the end of the period
	Shareholding ratio of the largest shareholder in CDI	Largest	Number of shares held by the largest shareholder / total shares
	Shareholding ratio of senior executives in China’s defence industry	CGB	Number of shares held by senior executives / total equity
	Proportion of independent directors in China’s defence industry	Dud	Number of independent directors / total number of directors
	Net interest rate of total assets of China’s defence industry	ROA	Proportion of net profit of national defence industrial enterprises to average total assets
	China’s national defence industrial enterprises	Dual	Is the general manager also the chairman of the board
	Industries of China’s national defence industrial enterprises	Industry	Dummy variable
	Year of China’s defence industry	Year	Dummy variable

To sum up, based on the previous research literature, guided by the innovation theory, Porter Hypothesis Theory and institutional theory, this paper uses the data of listed companies of China’s A-share market from 2007 to 2021 as the research object, trying to explore the ER on the TIE-DI, and starting from the EPC, to explore its moderating effect between the two.

Research design

Data source and variable definition

This paper selects the data of Shanghai and Shenzhen A-share listed companies from 2007 to 2021 as samples, and makes full use of the data processing software MATLAB to process and integrate. The main variable data are from China Intellectual Property Office, China Statistical Yearbook, China Environmental Statistical Yearbook and WIND database. After eliminating the samples of ST, financial industry and key elements, 1395 observations were obtained. The definitions of explained variables, explanatory variables, regulatory variables and control variables selected in this paper are shown in Table 1.

Model construction

(1) The direct effect model of ER and TIE-DI

To test the overall effect of ER on TIE-DI, as shown in Model (1) for details. The paper uses Herfindahl index to measure the competitiveness of ER and test its effect on TIE-DI [14], as shown in Model (2). This paper measures the variability of ER by measuring the fluctuation of sales revenue after industry adjustment, and tests its effect on TIE-DI, as shown in Model (3).

$$\begin{aligned}\ln\mathrm{TIECDI} &= \alpha_0 + \beta_1\mathrm{ERDIE} + \beta_2\mathrm{SCDI} + \beta_3\mathrm{Largest} + \beta_4\mathrm{Lev} + \beta_5\mathrm{CGB} \\ &+ \beta_6\mathrm{CDIEV} + \beta_7\mathrm{ROA} + \beta_8\mathrm{Dud} + \beta_9\mathrm{Dual} + \varepsilon\end{aligned} \tag{1}$$

$$\begin{aligned}\ln\mathrm{TIECDI} &= \alpha_0 + \beta_1\mathrm{EFE} + \beta_2\mathrm{SCDI} + \beta_3\mathrm{Largest} + \beta_4\mathrm{Lev} + \beta_5\mathrm{CGB} \\ &+ \beta_6\mathrm{CDIEV} + \beta_7\mathrm{ROA} + \beta_8\mathrm{Dud} + \beta_9\mathrm{Dual} + \varepsilon\end{aligned} \tag{2}$$

$$\begin{aligned}\ln\mathrm{TIECDI} &= \alpha_0 + \beta_1\mathrm{ECE} + \beta_2\mathrm{SCDI} + \beta_3\mathrm{Largest} + \beta_4\mathrm{Lev} + \beta_5\mathrm{CGB} \\ &+ \beta_6\mathrm{CDIEV} + \beta_7\mathrm{ROA} + \beta_8\mathrm{Dud} + \beta_9\mathrm{Dual} + \varepsilon\end{aligned} \tag{3}$$

(2) The direct effect model of EPC and TIE-DI

Based on the least square method (OLS), this paper examines the impact of EPC on TIE-DI, as shown in Model (4) for details. The maximisation likelihood function is equivalent to the minimisation cost function of the least square method, which also shows that it is reasonable to take the sum of error squares as the best fitting criterion. Therefore, the principle of the least square method is that the error satisfies the maximum likelihood estimate of the normal distribution.

$$\begin{aligned}\ln\mathrm{TIECDI} &= \alpha_0 + \beta_1\mathrm{CEPE} + \beta_2\mathrm{SCDI} + \beta_3\mathrm{Largest} + \beta_4\mathrm{Lev} + \beta_5\mathrm{CGB} \\ &+ \beta_6\mathrm{CDIEV} + \beta_7\mathrm{ROA} + \beta_8\mathrm{Dud} + \beta_9\mathrm{Dual} + \varepsilon\end{aligned} \tag{4}$$

(3) ER, EPC and TIE-DI

In order to verify the moderating effect of EPC on ER and TIE-DI, the interaction term $\mathrm{ERDIE}\cdot\mathrm{CEPE}$ between ER and EPC was added, which is detailed in Model (5). To verify the moderating effect of EPC on environmental flexibility and TIE-DI, the interaction term $\mathrm{EFE}\cdot\mathrm{CEPE}$ between environmental flexibility and TIE-DI was added, as shown in Model (6). To verify the moderating effect of EPC on environmental variability and TIE-DI, the interaction term $\mathrm{ECE}\cdot\mathrm{CEPE}$ between environmental variability and TIE-DI was added, as shown in Model (7).

$$\begin{aligned}\mathrm{lnTIECDI} &= \alpha_0 + \beta_1\mathrm{ERDIE} + \beta_2\mathrm{CEPE} + \beta_3\mathrm{ERDIE}\cdot\mathrm{CEPE} + \beta_4\mathrm{SCDI} + \beta_5\mathrm{Largest} \\ &+ \beta_6\mathrm{Lev} + \beta_7\mathrm{CGB} + \beta_8\mathrm{CDIEV} + \beta_9\mathrm{ROA} + \beta_{10}\mathrm{Dud} + \beta_{11}\mathrm{Dual} + \varepsilon\end{aligned} \tag{5}$$

$$\begin{aligned}\mathrm{lnTIECDI} &= \alpha_0 + \beta_1\mathrm{CEPE} + \beta_2\mathrm{EFE} + \beta_3\mathrm{CEPE}\cdot\mathrm{EFE} + \beta_4\mathrm{SCDI} + \beta_5\mathrm{Largest} \\ &+ \beta_6\mathrm{Lev} + \beta_7\mathrm{CGB} + \beta_8\mathrm{CDIEV} + \beta_9\mathrm{ROA} + \beta_{10}\mathrm{Dud} + \beta_{11}\mathrm{Dual} + \varepsilon\end{aligned} \tag{6}$$

$$\begin{aligned}\mathrm{lnTIECDI} &= \alpha_0 + \beta_1\mathrm{CEPE} + \beta_2\mathrm{ECE} + \beta_3\mathrm{CEPE}\cdot\mathrm{ECE} + \beta_4\mathrm{SCDI} + \\ &\beta_5\mathrm{Largest} + \beta_6\mathrm{Lev} + \beta_7\mathrm{CGB} + \beta_8\mathrm{CDIEV} + \beta_9\mathrm{ROA} + \beta_{10}\mathrm{Dud} \\ &+ \beta_{11}\mathrm{Dual} + \varepsilon\end{aligned} \tag{7}$$

Empirical research results and analysis

Descriptive statistical analysis

lnTIECDI is 0, the average value is 0.207, the maximum value is 2.965, and the standard deviation is 0.635. On the whole, the environmental performance of CDI is much higher than their own height, which shows that they also pay attention to the protection of environmental elements and improve the environmental management ability and technical level in the development process. The mean value of EFE was –0.259, the minimum value was –0.905, and the maximum value was –0.02. The mean value of ECE was 1.450, the minimum value was 0.109, the maximum value was 6.964, and the standard deviation was 0.965, indicating that each defence industry enterprise dealt with different degrees of environmental fluctuations. Therefore, our national defence industry environmental performance level is still in the low level. But compared with foreign countries, there is still a big gap. The results of EFE reflects that the environmental fluctuation degree of each CDI is different. Therefore, the environmental performance level of CDI is still at a low level. In general, compared with other industries, CDI faces more complex environmental factors, mainly displayed as: political factors, economic factors, social factors and technical factors. Different types of CDI are in different environmental policy.

Multiple regression analysis

Based on the joint effect of environmental flexibility and variability, the regression coefficient between ER and TIE-DI is 0.0965, significant value is less than 0.01, which indicates that ER can stimulate the vitality and motivation of TIE-DI. When analysing the impact of ER, environmental flexibility and environmental variability on the TIE-DI, the coefficient and T value of each control variable change little, indicating that the fixed effect is relatively stable.

After adding the interaction item of EPC and environmental variability, ECE·CEPE has a significant negative correlation at the 1 % level, and its regression coefficient is –0.0632, which indicates that if the EPC of CDI is strengthened, the inhibitory effect of environmental dynamic fluctuation on the TIE-DI will be deepened. The research shows that when analysing the effects of ER. Environmental flexibility, environmental variability on the TIE-DI, the coefficient and T value of each control variable change little, indicating that the fixed effect is relatively stable.

Policy proposal

First, appropriate and detailed environmental regulatory standards should be established for CDI, environmental policies should be improved, and more financial and technological support should be given to the efficiency of TIE-DI. According to the fluctuation of external market environment, competition degree and other heterogeneous factors, the implementation of differentiated management strategies, appropriate punitive measures to achieve both rewards and punishments, give full play to the advantages of the visible hand of national policy [15]. The complexity of environmental policies can significantly stimulate the technological innovation efficiency of CDI, and environmental regulations will have a moderating effect on the relationship between them. Therefore, the government should adopt incentive policies such as subsidies to provide funds for energy conservation and emission reduction of CDI when they are faced with large environmental dynamic fluctuations, alleviate the financing difficulties of CDI, especially small and medium-sized CDI, improve efficiency and promote TIE-DI.

Second, we should improve a fair, open, transparent and just industry environment for CDI and strengthen the dominance of the market. It is necessary to connect the visible hand of the government, the complexity of appropriate environmental policies, with the invisible hand of the market, establish a high-quality market innovation environment through the guidance of appropriate environmental policies, point out the direction for various types of subjects, and improve TIE-DI.

Third, establish a sound internal governance mechanism and information disclosure mechanism of CDI. CDI need to face the increasing uncertainty and the fluctuation of external market environment, which is unpredictable and random. Therefore, it is necessary to make the information of CDI transparent, provide useful and timely information to external investors in combination with internal supervision, improve the efficiency of external financing, and alleviate the problem of information asymmetry. To provide financial support for TIE-DI.

Conclusion

This paper analyses and tests ER from single environmental variability to environmental flexibility and variability, and discusses the relationship between ER, EPC and TIE-DI. After in-depth analysis. The greater the ER, the more it can promote the TIE-DI. For environmental flexibility, the more fierce the market competition faced by the CDI, the more it can promote the TIE-DI. On the contrary, for the environmental variability, when the CDI are faced with large sales fluctuations, they will reduce the technological innovation efficiency activities, that is, environmental changes hinder the TIE-DI. In addition, the "compensation effect" between the EPC and TIE-DI. The CDI produce products and reduce the production cost, which indicates that the EPC can significantly promote the TIE-DI. Finally, EPC has a moderating effect on ER and TIE-DI. From two aspects of environmental flexibility and variability, the interaction between EPC and ER was added into the regression model. The theoretical significance of this paper lies in the improvement of the new development mode of industrial enterprises under technological innovation and environmental policy change. The practical significance lies in helping to realise the high quality development of defence industry enterprises with the purpose of green development.

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