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Original scientific paper

A Comparative Empirical Study on the Product R&D Capability of Manufacturing Industry

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Abstract: Since the stage of Industry 4.0, high-end product design and new technology development have become the key to manufacturing innovation for some countries. As the foundation and carrier of high-tech industries, manufacturing is an important guarantee for national security, and companies engaging in manufacturing should make efforts to improve their product R&D capability while paying attention to economic benefits. However, there is still a lack of feasible index system to evaluate the product R&D capability of manufacturing industry. For the purpose, through the research methods of index evaluation and empirical analysis, this paper took the Chinese manufacturing industry as subject, selected 1344 companies in 28 industries as research samples. Then, this paper analyzed the situation of some sample companies in detail, discussed the product R&D conditions of current manufacturing companies from a few perspectives: inside, outside, and the industry. The results showed that the current product R&D capability of China's manufacturing industry can be divided into three levels. This paper provided a practical evaluation model for the manufacturing industry and contributed to policy recommendations.

Keywords: China; empirical study; innovation; manufacturing industry; product R&D capability

1 INTRODUCTION

In a society whose economy is driven by knowledge, main forms of knowledge assets are products and services, which could reflect the knowledge level of companies' products and services. The innovation performance evaluation of new products is the crux for assessing new product knowledge reserve, and developing new products is an important activity for companies to improve operating efficiency and maintain competitive advantages. Most countries in the world agree that science and technology are the primary productive forces, so they generally attach great importance to investment in scientific research. According to data released by the OECD (Organization for Economic Cooperation and Development) in 2021, the United States continues to rank the first in the world in terms of R&D expenditure, and the number is 612.7 billion US dollars in 2019. Judging from growth trend, the growth rate of China's R&D investment is significantly higher than that of other countries, it ranks the second ever since it has overtook 27 European Union countries in 2015, and its R&D expenditure in 2019 is 514.8 billion US dollars.

Chinese companies' R&D investment has increased significantly in recent years. In 2021, the total R&Dinvestment in China reached 2786.4 billion yuan, showing a 14.2% growth compared with the number of 2020, and the growth rate accelerated by 4.0% year-on-year. Of the TOP 2500 R&D investment companies globally in 2019, the R&D investment of US companies is 347.7 billion euros, accounting for 38.45% of the global total; EU companies invested 188.9 billion euros, accounting for 20.89% of the global total; the R&D investment of Chinese companies is 118.8 billion euros, accounting for 13.14%; and the R&D investment of Japanese companies is 114.9 billion euros, accounting for 12.71%. However, in contrast to the ever-growing huge R&D investment, in China, the R&D output has always been at a low level, so researching how to rationally and effectively allocate R&D resources, improve operating efficiency, and enhance output capacity is of great practical significance.

Manufacturing is the pillar industry in national economy. Now in China, industrialization is still in process and the progress of manufacturing has an important impact on economic development. As the foundation and carrier of high-tech industries, manufacturing is not only an important guarantee for national security, but also the basis, bridge, and channel for transforming high-tech into productivity and new technological achievements into products. Thus, vigorously promoting scientific and technological advancement is a crucial issue for realizing industrial transformation and upgrading in China.

As industrial age has entered a stage of Industry 4.0, high-end product design and new technology development have become the key to manufacturing innovation for some countries. In the context of economic globalization, new emerging industries driven by information technologies are developing at a fast pace, and only by taking innovation as the sole path could we better helm the direction for these industries. Therefore, designing new products, developing new R&D technologies, and improving service quality should be taken as key steps for the development of manufacturing industry in the future. At the same time, the central and local governments should strengthen the protection of intellectual property rights. However, some companies have not realized the importance of R&D yet, and this is the main reason why there are still many low-quality products in the market at present. To face the increasingly fierce market competition at home and abroad, Chinese manufacturing companies must change their traditional business idea, regard R&D as an important strategy for sustainable development, and increase the conversion rate of innovation achievements by enhancing independent product R&D capability, thereby winning in market competition with high-quality products and services.

In terms of improving innovation quality, China is entering a transitional period, since China has proposed to establish a national system of innovation, and numerous scholars have enriched theories about the connotation of innovation ability, the improvement of evaluation criteria, and the exploration of evaluation methods. However, research on theories of product R&D capability of Chinese manufacturing industry needs to be deepened, and there is not an Evaluation Index System (EIS) for assessing the product R&D capability of Chinese manufacturing industry, and a set of scientific EIS is required for correctly evaluate the product R&D capability of Chinese manufacturing industry. This could serve a good foundation for objectively evaluating the product R&D capability of manufacturing companies and point out the right direction for the development of Chinese manufacturing industry. Besides economic benefits, the manufacturing industry should also pay attention to economic efficiency, innovation ability, and the ability to develop resource and environment co-ordinately. To develop national economy in a rapid and healthy way, we should possess core technologies in critical areas related to national security and economy. Innovation ability of companies is the foundation for the innovation ability of the country, and companies are subjects of innovation activities, so we must treat the issue of enhancing product R&D capability of companies as a strategic task.

However, there was still a lack of perfect and practical evaluation model to measure the product development capability of manufacturing industry. Therefore, in order to effectively guide enterprises to measure the importance of their own investment in innovation and provided a quantifiable basis for policy makers, this paper used the index evaluation method and the empirical analysis method to carry on the research. Following related principles, this paper proposed an EIS for product R&D capability of manufacturing companies. From the perspective of manufacturing companies, the product R&D capability can be defined as a company's ability to integrate various internal and external innovation resources, establish new R&D platforms, and promote the organization to innovate the design, manufacturing, and structure, thereby enhancing its comprehensive competition strength, winning core technologies, and forging brand image under the condition that the company has a powerful economic strength.

Innovation points in this paper include: (1) This paper enriched models for measuring the product R&D capability of manufacturing companies, and provided theoretical support for these companies to enhance their product R&D capability; (2) The paper gave a vertical comparison of 1344 listed manufacturing companies in 28 industries, and calculated the development level of the product R&D capability of each industry; (3) The proposed evaluation model fully considered the external and internal factors, and could give suggestions to both the government and the companies.

2 LITERATURE OVERVIEW

2.1 Concept and Features of Product R&D Capability

Scholar Schumpeter proposed the concept of innovation in 1912, he believes that innovation is to create a new production function to re-combine production factors and conditions, and introduce them into the production system, and its goal is to gain the potential excess profits.

Overall speaking, innovation requires intellectual property rights and technological innovation. R&D is necessary for the acquisition of new knowledge and technology, and innovation is the outcome attained by a company's multiple abilities, including its technological innovation ability, comprehensive R&D ability, and technological improvement ability, etc.

Lengnick-Hall [1] holds that innovation is a practice conducted by companies to comprehensively utilize their manpower, material and financial resources, and the kernel of innovation is that an innovation subject carries out various innovation activities to create innovation results and corresponding rights and values. According to Guan and Ma [2], technological innovation ability is a kind of resource containing multiple dimensions including products, processes, and techniques. Burgelman et al. [3] points out that technological innovation ability is a comprehensive ability of a company to implement relevant measures to succeed in technological innovation, and it contains the abilities to allocate resources, take lead, and make predictions. Moreover, Shapiro [4] discussed the concept and composition of companies' innovation ability. Scholars Lemon and Sahota [5] studied the factors affecting the improvement of companies' innovation ability and proposed a few measures for that.

2.2 Influencing Factors of Product R&D Capability

Influencing factors of product R&D capability are the driving force for companies to carry out product R&D. After reviewing existing literature, it is found that scholars generally believe that these influencing factors can be roughly divided into internal factors and external factors. Typical internal factors include: entrepreneurial streak (such as behaviour features of organization managers and entrepreneurial spirit), core innovation capabilities (such as interactive learning ability and resource integration ability), innovation output capabilities (such as profit level, innovation pressure, innovation confidence, innovation atmosphere, and R&D system), and features of the organization (such as the structure and size of the organization). External factors refer to external resources the companies rely on for innovation, and the external environment features of the companies, such as resource market structure, macro policy environment, industrial innovation process, intellectual property protection, and external pressure.

New products are those products developed and manufactured using new technical principles and new design concepts, compared with original products, they have obvious improvements in structure, materials, or manufacturing processes, and they could exhibit higher performance or extended functions. Brown and Eisenhardt [6] believe that new product development is the decisive factor for the survival and development of companies, and it is an important source of their competitive advantages. Song and Parry [7] argue that advanced manufacturing technologies and product designs can help new-type service sector companies meet unconventional market needs more effectively than their competitors. Szymanski and Henard [8] think that new product differentiation allows unique product positioning based on innovative technologies and designs, which in turn improves the ability of companies to forecast, design, and deliver innovative products more popular and easier to sell than their competitors, thereby avoiding the potential threats caused by the imitation of competitors. Mallick and Schroeder [9] surveyed a few professionals participating in product R&D projects in high-tech electronics industry and discovered a few facts: (1) In high-tech manufacturing industry, the success of new product R&D is determined by market share; (2) The increase of market share is driven by the unit cost of arable land; (3) The decrease of unit cost is mainly driven by the acceleration of new product R&D, not by the R&D budget; wherein the higher technical performance and the faster new product R&D speed are not the leading reasons. Sorescu and Spanjol [10] discovered that as product life cycle is shortening and customer needs become more diverse, the competitive advantages of conventional products centered on quality and cost are weakening, so more companies take the constant new product R&D as an important means to mine their competitive advantages and gain new sources of profit.

Chen et al. [11] pointed out that new product development is an important part of corporate strategy. Under the condition that consumer needs and market environment are ever-changing, accelerating the development of new products can help companies establish and maintain their competitive advantages. Caner et al. said that new product development involves the integration of diverse knowledge, which requires companies to possess unique internal knowledge and the ability to acquire critical knowledge across fields [12, 13]. Yu et al. [14] evaluated the performance of new product innovation in high-tech industries of China, and figured out that the main ways of product R&D are invention patents, utility model patents, design patents, and production process optimization, wherein invention patents are the best way of product R&D; the funds of new product development, and the companies' R&D expenditure and new product sales revenue have significant positive impact on invention patents, that is, it is conducive to the improvement of invention patents.

Innovation-driven is a prerequisite for companies to grow or gain competitive advantages, and enhancing the product R&D and production ability are key points for companies to maintain and strengthen their competitiveness. Rehfeld et al. [15] believe technology-driven, customer satisfaction, company size, and company age have significant impact on product innovation, policies serve as an impetus of production innovation, but its effect is not that obvious. Cucculelli and Ermini [16] studied the impact of product innovation on corporate growth and found that the development of new products has increased companies' opportunities for growth, especially on those with significant innovation tendency, high R&D intensity, and strong absorption capacity, such effect is more prominent. Schoenherr et al. [17] used a theoretical model established based on resource advantage theory to test the collected data of 195 small and medium-sized companies in the manufacturing industry, and the results indicated that knowledge capital can promote product R&D, and market orientation and technology opportunities are the two main determinants for companies to gain competitive advantages and improve performance and profits. Chuang et al. [18] argue that new product projects need to combine customer-oriented learning, competitor-oriented learning, and product R&D capability; the authors surveyed 187 high-tech companies in China and found that different combinations of customer-oriented learning, competitor-oriented learning, and product R&D capability have positive impact on the success of new product projects. Ringen and Welo [19] modeled the relationship between product R&D performance and key knowledge components based on survey results from Norwegian manufacturing companies, and found that the product R&D researchers' thought of exploring new innovation ideas and structural knowledge processes gets stronger under specific resource, time, and cost conditions.

Table 1 Factors that may affect the product R&D capability of manufacturing companies

Dimension	Category	Influencing factors
External factors	Industry	Technology development level
		Demand growth trend
		Market competition
	Location	Infrastructure construction
		Partnership building
		Cultural environment
	Government policy	Intellectual property protection system
		Risk sharing mechanism for product R&D
		Government financial support
		Innovation service environment
Internal factors	Basic features of the company	Company size
		Ownership structure
	Development strategy of the company	Development strategy
		Specialization strategy and diversification strategy
		Internationalization strategy
		Differentiation strategy
		Low cost strategy
		Continuous competitive advantage
	Organizational structure of the company	Centralized decision-making
		Fully-empowered decision-making
		Department connectivity
	Organizational culture of the company	Innovation resistance
		Total quality management
		Innovation culture
	Management team of the company	Project leader
		Accumulation of historical experience
		Cost and risk awareness
		Innovation return awareness
	Functions and assets of the company	Resources and capabilities
		Marketing strategy
		Supervision of competitors
		Advanced equipment and technology
		Production capacity utilization
		Seniority, qualification, and experience
		Human resource development
		Accessibility of innovation funds

Qu and Chen [20] explored the relationship between innovation-driven, absorption capacity, and innovation performance of new products, and drew the conclusion that invention patents have good development potential and can make significant contributions to conventional products. Oztemel and Ozel [21] discussed the impact of innovation ability of small-sized low technological level manufacturing companies on their product innovation performance. The author believes that cognition ability, social interaction, thought management, creativity implementation, and collaboration with stakeholders and competitors in interactive learning, are factors affecting the innovation ability. Hallstedt et al. [22] regard digitalization, sustainability, and serviceability as conditions for manufacturers to develop their products. The authors conducted semi-structured interviews with small, medium and large Swedish manufacturing companies, and the research findings suggest that knowledge management platforms, data management platforms, a set of standards and indicators for measuring progress, and methods and tools for defining, modeling and evaluating solutions are important factors for enhancing product R&D capability.

After reviewing related literature, it is found that most existing studies get to the problem from angles such as innovation input, production, management, output, and marketing, now there is not a uniform standard for evaluating the product R&D capability of companies, especially manufacturing companies. Factors affecting the product R&D capability of manufacturing companies can be considered from two dimensions, internal and external. External factors include the features of engaging industry, location place, and government policy; internal factors include the companies' basic features, development strategy, organizational structure, company culture, management team, and functions and assets of the company. After summarizing existing works, this paper holds that the following factors listed in Tab. 1 can affect the product R&D capability of manufacturing companies.

In the study of Ma et al. [23] on new product development capability, regression analysis was carried out from two dimensions of technology management and technology capability by using questionnaire survey method. Although questionnaire survey is more intuitive and professional, it is difficult to directly summarize the evaluation criteria, and it ignores the calculation of the influence of external factors. Xu et al. [24] believe that different types of invention capability will have a major impact on the new product development performance of an enterprise. By classifying the invention capability of an enterprise, regression analysis method is used for research. Therefore, based on the evaluation indicators in Tab. 2, combined with the index evaluation method and empirical analysis, this paper adopts multiple regression analysis to conduct research.

Table 2 Definitions of independent variables

Type	Independent variable	Definition
Internal factors	Resource investment ability (*A*1)	R&D input intensity (*A*11)
		R&D personnel input intensity (*A*12)
		R&D capital input intensity (*A*13)
	Management ability (*A*2)	Innovation strategy (*A*21)
		Innovation mechanism (*A*22)
		Innovation speed (*A*23)
		Innovation quality of entrepreneurs (*A*24)
	Marketing ability (*A*3)	The proportion of marketing expenses of independently innovated products in total marketing expenses (*A*31)
		Market share of independently innovated products (*A32*)
		The proportion of marketing personnel in the total number of employees (*A*33)
	Environmental protection ability (*A*4)	Comprehensive energy consumption for per 10,000 Yuan output value (*A*41)
		Rate of industrial wastewater reaching discharge standards (*A*42)
		Comprehensive utilization rate of industrial solid waste (*A*43)
External factors	Institutional and policy environment (*A*5)	The proportion of government financial input in total R&D funds of the company (*A*51)
		The proportion of product tax preferences in total product sales revenue (*A*52)
	Market and legal environment (*A*6)	Intensity of intellectual property protection (*A*61)
		Regional innovation and entrepreneurship index (*A*62)
	Education and R&D environment (*A*7)	The proportion of other company R&D investment in total R&D investment of the company (*A*71)
		The proportion of scientific research achievements adopted by the company in the total scientific research achievements of the company (*A*72)

3 DATA AND METHODOLOGY
3.1 Case Study for Product R&D Capability Measurement
3.1.1 Dependent Variable

In this paper, the product R&D capability of manufacturing industry (*P*) was taken as the dependent variable of the empirical research model, and it was defined as the sum of the number of patent applications, the number of invention patent applications, the number of utility model patent applications, and the number of design patent applications.

3.1.2 Independent Variables

In this paper, the empirical research model for measuring the product R&D capability of manufacturing industry was built from two perspectives: internal factors and external factors. Internal factors include: resource investment ability, management ability, marketing ability and environmental protection ability. External factors include: institutional and policy environment, market and legal environment, and education and R&D environment. The definitions of independent variables are shown in Tab. 2.

Extreme value processing was adopted to nondimensionalize the data. Due to the large differences in indicators, the directly standardized data was of low credibility, so before standardization, each indicator was processed respectively by methods of taking logarithm or sectionalized value assignment; and the quartile method was adopted to estimate missing data, wherein, *i* represents the manufacturing company; *j* represents the evaluation indicator, x_{ij} represents the data of the *j*th indicator of the *i*th manufacturing company before and after standardization processing; *n* represents the number of manufacturing companies, the basic formula for data standardization is:

$$X_{ij}=\frac{x_{ij}-\min\left(x_{1j},x_{2j},...,x_{nj}\right)}{\max\left(x_{1j},x_{2j},...,x_{nj}\right)-\min\left(x_{1j},x_{2j},...,x_{nj}\right)}$$

Based on existing research, the least square method was adopted to investigate the influence of various factors on the product innovation ability of manufacturing industry, as shown in the following formula:

$$P=\beta_0+\beta_1A_1+\beta_2A_2+\beta_3A_3+\beta_4A_4+\beta_5A_5+\beta_6A_6+\beta_7A_7+\varepsilon$$

3.2 Data Source and Processing

In view of the availability of data related to product R&D capability of manufacturing industry, in this paper, several manufacturing companies in China in 2020 were selected as subjects. The samples come from various industries including electrical machinery and equipment manufacturing; apparel and accessories industry; textile industry; non-metallic mineral products industry; waste resource comprehensive utilization industry; ferrous metal smelting and processing industry; chemical fiber manufacturing industry; chemical raw materials and chemical products manufacturing industry; computer, communications and other electronic equipment manufacturing industry; furniture manufacturing industry; metal products manufacturing industry; alcohol, beverage, and refined tea manufacturing industry; wood processing and wood, bamboo, rattan, palm, grass products manufacturing industry; agricultural and agrifoods processing industry; leather, fur, and feather products processing and shoemaking industry; automobile manufacturing industry; food manufacturing industry; railway, vessel, aerospace and other transportation equipment manufacturing industry; general machinery manufacturing industry; culture, education, arts&crafts, sports and entertainment products manufacturing industry; rubber and plastic products manufacturing industry; pharmaceutical manufacturing industry; instrument manufacturing industry; printing and recording medium reproduction industry; non-ferrous metal smelting and processing industry; paper and paper products manufacturing industry; specialized equipment manufacturing industry and other manufacturing industries. The data of 1354 listed companies was collected, and the data sources include the annual reports of these companies, Chinese Enterprise Innovation Survey Yearbook, China Statistics Yearbook on Energy, China Statistics Yearbook on Environment, China marketization index, and the corporate social responsibility index published on Hexun (https://www.hexun.com/). All missing data was subjected to interpolation processing.

4 RESULTS AND DISCUSSIONS

In this study, each variable and the regression model were tested by descriptive analysis, correlation test and multiple regression analysis to determine the credibility of model's explanatory ability and attain final regression results, thereby determining the correlation between each influencing factor and the product R&D capability of the manufacturing industry.

4.1 Descriptive Statistical Analysis

4.1.1 Descriptive Statistical Analysis of Dependent Variable

At first, the dependent variable (product R&D capability of manufacturing industry) was statistically analyzed according to the industry. Tab. 3 gives the statistical analysis of product R&D capability of the manufacturing industry.

Table 3 Descriptive statistical analysis

Industry	*n*	Mean.	Std.	Min.	Max.
Electrical machinery and equipment manufacturing industry	150	0.8311	0.0000	0.0183	0.0706
Apparel and accessories industry	14	0.0169	0.0000	0.0032	0.0046
Textile industry	14	0.0156	0.0000	0.0034	0.0046
Non-metallic mineral products industry	48	0.1332	0.0000	0.0128	0.0276
Waste resources comprehensive utilization industry	3	0.0118	0.0007	0.0061	0.0056
Ferrous metal smelting and processing industry	14	0.0215	0.0002	0.0045	0.0063
Chemical fiber manufacturing industry	8	0.0154	0.0003	0.0044	0.0053
Chemical raw materials and chemical products manufacturing industry	150	0.0402	0.0000	0.0033	0.0056
Computer, communications and other electronic equipment manufacturing industry	241	0.4458	0.0000	0.0131	0.0378
Furniture manufacturing industry	13	0.1174	0.0005	0.0223	0.0353
Metal products manufacturing industry	36	0.0292	0.0001	0.0048	0.0068
Alcohol, beverage, and refined tea manufacturing industry	6	0.0004	0.0000	0.0002	0.0002
Wood processing and wood, bamboo, rattan, palm, grass products manufacturing industry	4	0.0081	0.0004	0.0043	0.0032
Agricultural and agrifoods processing industry	15	0.0335	0.0000	0.0052	0.0090
Leather, fur, and feather products processing and shoemaking industry	4	0.0277	0.0001	0.0081	0.0132
Other manufacturing industry	9	0.0089	0.0004	0.0031	0.0033
Automobile manufacturing industry	59	1.0000	0.0001	0.0276	0.1299
Food manufacturing industry	21	0.0194	0.0001	0.0021	0.0042
Manufacturing of railway, shipping, aerospace and other transportation equipment industry	22	0.0300	0.0001	0.0055	0.0078
General equipment manufacturing industry	75	0.0923	0.0000	0.0085	0.0134
Railway, vessel, aerospace and other transportation equipment manufacturing industry	9	0.0358	0.0001	0.0128	0.0133
Rubber and plastic products manufacturing industry	55	0.0754	0.0000	0.0063	0.0132
Pharmaceutical manufacturing industry	131	0.3378	0.0000	0.0044	0.0296
Instrument manufacturing industry	39	0.0484	0.0000	0.0101	0.0125
Printing and recording media reproduction industry	6	0.0101	0.0000	0.0050	0.0039
Nonferrous metal smelting and processing industry	35	0.0328	0.0000	0.0049	0.0075
Paper and paper products manufacturing industry	15	0.0350	0.0000	0.0069	0.0118
Special equipment manufacturing industry	148	0.3996	0.0000	0.0123	0.0350
All	1344	1.0000	0.0000	0.0103	0.0432

Overall speaking, among all industries, the average value of product R&D capability of 668 listed companies in 7 industries was above the average value of the overall disclosure index, and the average value of product R&D capability of 676 listed companies in 21 industries was below the average of the overall disclosure index. The average value of product R&D capability of all industries was 0.0103, which was far from the highest level of 1.0000, and this indicates that the awareness of manufacturing industry for product R&D capability was generally insufficient and the overall capability was weak, therefore, it needs policy incentives from the government. Moreover, it can also be observed that the product R&D capability of different industries was not balanced and varied greatly, which may be related to the attributes of the industry, wherein the average value of carbon accounting information disclosure index of the automobile manufacturing industry was the highest, followed by the furniture manufacturing industry, and the electrical machinery and equipment manufacturing industry, their average values were 0.0276, 0.0223, and 0.0183 respectively, indicating that the product R&D capability of these three industries was higher than that of other industries, they were enthusiastic about product R&D, but there was still a large gap compared with the highest level. The average product R&D capability of other manufacturing industry, food manufacturing industry, wine, beverage and refined tea manufacturing industry was lower than that of other industries, the values were 0.0031, 0.0021, and 0.0002, respectively, and the sample number was small, indicating that the sample companies in these industries had seldom or never carried out product R&D.

4.1.2 Descriptive Statistical Analysis of Independent Variables

Tab. 4 gives the descriptive statistical analysis results of independent variables. After the data was subjected to standardization, the maximum and minimum values of each variable were 1.0000 and 0.0000. This paper adopted the quartile method to perform descriptive statistical analysis on independent variables.

According to the table, among internal factors, the average value of resource investment ability was 0.1719, the upper quartile was 0.0872, the lower quartile was 0.2035, the scale span was small, indicating that insufficient resource endowment in the product R&D capability of manufacturing industry is a common phenomenon, and companies should pay attention to it. In terms of management ability, the average value was 0.6401, the upper quartile was 0.5116, the lower quartile was 0.8607, indicating that the sample companies perform well in terms of management ability and they generally have a consciousness of creation and innovation. In terms of marketing ability, the average value was 0.6749, the upper quartile was 0.5210, the lower quartile was 0.8213, indicating that the performance of sample companies is good in this aspect and they generally lay emphasis on sales and marketing works. In terms of environmental protection ability, the average value was 0.4333, the upper quartile was 0.3323, the lower quartile was 0.5607, the overall performance was at a low level, indicating that more effort is needed for the energy conservation and emission reduction work of manufacturing industry to realize goals of carbon neutralization and carbon peak. Among external factors, the average value of institutional and policy environment was 0.7105, indicating that currently the government has provided a social environment suitable for the development and innovation of the manufacturing industry, the upper quartile was 0.6557 and the lower quartile was 0.7539, suggesting that the difference of institutional and policy environment between each region was not obvious. In terms of market and legal environment, the average value was 0.7000, the upper quartile was 0.4571, the lower quartile was 0.9390, the standard deviation was 0.2756, the difference was large, indicating there are large differences in the degree of marketization between different regions, and this also means that the selected samples have covered a large range and the data is comprehensive. In terms of education and R&D environment, the average value was 0.3668, the upper quartile was 0.1709, and the lower quartile was 0.5658. The overall performance of sample companies was not good, indicating that for current education and R&D environment, there is still much room for development.

Table 4 Descriptive statistical analysis of independent variables

Variables	*n*	Mean	Std.	Min.	*P*25	Median.	*P*75	Max.
A1	1344	0.1719	0.1390	0.0000	0.0872	0.1251	0.2035	1.0000
A2	1344	0.6401	0.2307	0.0000	0.5116	0.7221	0.8607	1.0000
A3	1344	0.6749	0.2334	0.0000	0.5210	0.7767	0.8213	1.0000
A4	1344	0.4333	0.1880	0.0000	0.3323	0.4628	0.5607	1.0000
A5	1344	0.7105	0.1101	0.0000	0.6557	0.7119	0.7539	1.0000
A6	1344	0.7000	0.2756	0.0000	0.4571	0.8138	0.9390	1.0000
A7	1344	0.3668	0.2005	0.0000	0.1709	0.3384	0.5658	1.0000

Table 5 Pearson correlation coefficients

	P	*A*1	*A*2	*A*3	*A*4	*A*5	*A*6	*A*7
P	1	-						
*A*1	0.087**	1	-					
*A*2	0.045	0.372**	1	-				
*A*3	0.017	0.305**	0.894**	1	-			
*A*4	0.056*	0.107**	0.036	0.036	1	-		
*A*5	0.003	0.126**	0.078**	0.039	−0.002	1	-	
*A*6	0.007	−0.052	0.028	0.007	−0.345**	0.619**	1	-
*A*7	0.150**	0.031	0.101**	0.052	−0.107**	0.524**	0.732**	1

Notes: **, * represents the level of significance at 1% and 5%, respectively.

4.2 Test of Correlation Between Variables

4.2.1 Correlation Analysis of Variables

Before performing regression analysis on the influencing factors of product R&D capability of manufacturing industry, at first, each variable was subject to correlation analysis to examine the correlation between each factor and the R&D capability and lay a foundation for subsequent research. Tab. 5 gives the Pearson correlation coefficients of all variables. Based on the test results given in the table, a preliminary judgment could be made on the correlation between product R&D capability of manufacturing industry and each independent variable.

According to Tab. 5, the product R&D capability of manufacturing industry (P) is significantly correlated with resource investment ability ($A1$) and education and R&D environment ($A7$) at a significance level of 1%, and is significantly correlated with environmental protection ability ($A4$) at a significance level of 5%, indicating that there is a possibility that the assumption made in this paper is valid, and it needs to be further verified in regression analysis. In addition, the correlation between independent variables needs to be tested, if there is significant multicollinearity, it can affect the accuracy of the regression model. Resource investment ability ($A1$) is significantly correlated with management ability ($A2$), marketing ability ($A3$), environmental protection ability ($A4$), institutional and policy environment ($A5$) at a significant level of 1%. Management ability ($A2$) is significantly correlated with marketing ability ($A3$), institutional and policy environment ($A5$) and education and R&D environment ($A7$) at a significant level of 1%. Environmental protection ability ($A4$) is significantly correlated with institutional and policy environment ($A5$), market and legal environment ($A6$), education and R&D environment ($A7$) at a significant level of 1%. Market and legal environment ($A6$) is significantly correlated with education and R&D environment ($A7$) at a significant level of 1%.

Under normal circumstances, multicollinearity occurs when the correlation coefficient between independent variables exceeds 0.9. According to the Pearson correlation coefficients shown in the table, the maximum absolute value of correlation coefficients is 0.894 < 0.9, so the possibility of multicollinearity is low.

4.2.2 Diagnosis of the Collinearity Problem of Independent Variables

Tolerance and Variance Inflation Factors (VIF) are reciprocal to each other and are an effective way to test multicollinearity (in Tab. 6). It is generally considered that when VIF is less than 10 and tolerance is greater than 0.1, there is no multicollinearity.

Table 6 Diagnosis of multicollinearity between independent variables

Variable	Tolerance	VIF
*A*1	0.8230	1.2150
*A*2	0.1860	5.3690
*A*3	0.198	5.061
*A*4	0.775	1.291
*A*5	0.545	1.836
*A*6	0.298	3.354
*A*7	0.429	2.329

According to the data in the table, the VIF of each variable is less than 6, and the tolerance is greater than 0.1, indicating that there is no multicollinearity between independent variables, and regression analysis can be carried out.

4.3 Multiple Regression Analysis

4.3.1 Significance Test of Regression Model

At first, R and R^2 were used to test the overall significance of the regression model, as shown in Tab. 7. Although the value of R^2 (0.048) after adjustment is small, the F-value (10.646) shows that the fitting result of the model as a whole is acceptable.

In addition, the Durbin-Watson statistics is an important method to test whether a model is self-correlated. In general, a Durbin-Watson statistic between 1.5 and 2.5 indicates no significant autocorrelation. According to Tab. 7, there is D-W = 1.979, which is between 1.5 and 2.5, so it can be considered that there is no significant autocorrelation in the regression model.

Table 7 Significance test of regression model

R	R^2	adj. R^2	F-value	Durbin-Watson
0.230	0.053	0.048	10.646	1.979

4.3.2 Significance Test of Regression Coefficients

According to Tab. 8, the p-values of management ability ($A2$), marketing ability ($A3$), and environmental protection ability ($A4$) are all greater than 0.1, indicating that these three variables failed to pass the significance test. Resource investment ability ($A1$), institutional and policy environment ($A5$), market and legal environment ($A6$), and education and R&D environment ($A7$) passed the significance test.

Table 8 Regression coefficients

	B	Std.	*t*	*Sig.*
(Constant)	0.018	0.009	2.059	0.040
*A*1	0.023	0.009	2.555	0.011
*A*2	0.011	0.012	0.964	0.335
*A*3	−0.013	0.011	−1.191	0.234
*A*4	−0.006	0.007	−0.836	0.403
*A*5	0.026	0.014	1.861	0.063
*A*6	0.025	0.008	3.253	0.001
*A*7	0.064	0.009	7.363	0.000

In Tab. 8, the coefficient of $A1$ is positive ($B = 0.023$) and has passed the significance test ($Sig. = 0.011 < 0.05$) at the level of 5%, indicating a positive correlation between resource investment ability and product R&D capability. More invested resource indicates a company has a stronger ability to acquire resource and a faster speed of recouping its investment. At the same time, the company can take strategic measures to promote innovation works and optimize its business structure so that it could develop in a sustainable way.

The coefficient of $A5$ is positive ($B = 0.026$), and has passed the significance test at the level of 10% ($Sig. = 0.063 < 0.1$), which is generally considered as acceptable, and it indicates that the institutional and policy environment is positively related to product R&D capability. In a region with better institutional and policy environment, companies could get more policy subsidies and incentives, and the more incentives the companies get, the better the independent innovation advantages of the companies in the region. In the meantime, government can bring some pressure, which can indirectly promote companies to carry out product R&D.

The coefficient of *A*6 is positive ($B = 0.025$), and it has passed the significance test at the level of 1% (*Sig*. = 0.001 < 0.01), indicating that market and legal environment is positively related to product R&D capability. The market and legal environment represents the degree of marketization and the intensity of intellectual property protection in a region. Manufacturing companies are usually in the upstream of a supply chain, and a good market environment could help upstream and downstream companies to cooperate, thereby improving their efficiency. Intellectual property protection can provide legal protection to companies and help enhance product R&D capability.

The coefficient of *A*7 is positive ($B = 0.064$), and it has passed the significance test (*Sig*. = 0.000 < 0.01) at the level of 1%, indicating that education and R&D environment is positively related to product R&D capability. The large coefficient indicates that among the selected influencing factors, the influence of education and R&D environment on product R&D capability is the most significant, that is, highly educated employees and researchers and high-tech industrial parks have a great impact on the product R&D capability of companies. When an innovation-orientated company picks its location, it needs to pay attention to the location advantages of a region.

After above tests, the regression coefficients of resource investment ability (*A*1), institutional and policy environment (*A*5), market and legal environment (*A*6), and education and R&D environment (*A*7) were substituted into the regression equation, then the following regression model was attained:

$P = 0.023\,A1 + 0.026\,A5 + 0.025\,A6 + 0.064\,A7$

5 CONCLUSIONS AND SUGGESTIONS

To figure out the current situation of carbon accounting information disclosure of listed companies in heavy pollution industries of China and its influencing factors, this paper analyzed the product R&D situation of 1344 listed companies in 28 manufacturing industries and selected several internal and external factors for theoretical analysis and modeling. According to empirical study results, the product R&D capability of Chinese manufacturing industries can be divided into three levels. High level industries include automobile manufacturing industry; furniture manufacturing industry; electrical machinery and equipment manufacturing industry; computer, communications and other electronic equipment manufacturing industry; non-metallic mineral products industry; culture, education, arts & crafts, sports and entertainment products manufacturing industry; and specialized equipment manufacturing industry. Low level industries include wood processing and wood, bamboo, rattan, palm, grass products manufacturing industry; textile industry; chemical raw materials and chemical products manufacturing industry; apparel and accessories industry; other manufacturing industry; food manufacturing industry; and wine, beverage and refined tea manufacturing industry. Now China's manufacturing industries are developing unevenly and incompletely, and product R&D is facing a series of problems such as insufficient R&D resource investment, insufficient awareness of companies for environmental protection, insufficient policy support, and few high-end talents. Stakeholders must take practical and effective measures to enhance product R&D capability. Therefore, in this context, Chinese manufacturing companies should make efforts to break through the current pattern, form their own technological advantages, become integrator of global industrial chain and value chain, and make breakthroughs in core technologies.

Scientific and technological revolution and the wave of economic globalization have changed the pattern of the division of global industries. In this context, the production processes with intensive resource & labor and high environmental cost led by transnational corporations have begun to shift to developing countries. Now the Chinese manufacturing industry has reached a global level but the insufficient R&D investment has resulted in a low R&D capability of common industrial technologies, which has directly affected the improvement of industrial competitiveness. Based on the research results attained above and the current development state of the product R&D capability of manufacturing industry, this paper proposed the following suggestions:

First, the key to enhancing product R&D capability of the manufacturing industry is still to strengthen innovation ability. The Chinese manufacturing industry should pay attention to basic innovation, original innovation and high-quality innovation, and strive to increase the number and proportion of invention patents. Companies engaging in manufacturing should increase R&D resources and capital investment, develop core technologies and break through bottle necks. Besides encouraging companies to apply for invention patents, the government should also give corresponding support and incentives.

Second, the Chinese manufacturing industry is entering a transition period of innovation quality improvement, and effective measures are urgently needed to promote transformation and upgrading. The government should create a good external environment for industrial transformation, such as the policy environment, education and talent environment, and natural environment. To achieve the carbon peaking and carbon neutrality goals, the government should also encourage and reward companies which have developed low-carbon technologies and applied for patents of green inventions.

Third, the funds for new product R&D of Chinese manufacturing industry are at a stage of increasing returns on scale. The sales revenue of new products is essentially an important reflection of company size, and expanding company size is conducive to improving the flexibility of new product R&D funds. So we should appropriately encourage small and medium-sized manufacturing to expand their production scale, increase product diversity, and improve the performance of product R&D funds.

Fourth, we can learn from the talent training model of other countries. The shortage of talents also limits the ability of independent research and development. The lack of mature intellectual property protection system has also become an important obstacle for enterprises to carry out technological innovation. We can learn from the German methods of training skilled workers and improve the capability to apply for practical patents.

Last, considering the accessibility and completeness of the data, this paper took data of year 2020 as samples. In addition, some internal factor data had not been disclosed in corporate annual reports. In the future, we hope to update the data for further analysis, and collect internal data from specific companies in a targeted manner for deeper explorations.

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