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# Study on the Indicators Evaluating Innovation Abilities of High-end Equipment Manufacturing Industry in Sichuan Province

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**Abstract:** Innovation is the only way to enhance the competitiveness of high-end equipment manufacturing industry in Sichuan province. However, due to the lack of relevant evaluation standards, many high-end equipment manufacturing enterprises cannot evaluate their own innovation abilities effectively. Using the expert-interview method, this paper constructs an evaluation index system composed of three primary indicators, six secondary indicators and nine tertiary indicators. This paper determines the weights for each indicator through order-relationship analysis, based on which suggestions are put forward to improve the innovation ability for such enterprises.

**Key words:** High-end equipment manufacturing industry; intelligent manufacturing; innovation ability; indicator system

## 1 Introduction

High end equipment manufacturing industry is a strategic emerging industry which is at the core link in the industrial chain and the high-end of the value chain. It produces high-tech products and is the key engine that is transforming and upgrading industries in Sichuan Province. According to the “ ‘13th five-year plan’ for the Development of Strategic Emerging Industries in Sichuan Province”, Sichuan Province will be built into a key national high-end equipment industry base in the next five years relying on its current development and resource conditions in high-end equipment manufacturing industries<sup>[1]</sup>. However, the lack of appraisal criteria for innovation ability results in the failure of many high-end equipment manufacturing enterprises in Sichuan to effectively evaluate their innovation ability; the unawareness about how to effectively improve their innovation ability also results in the reduction in such abilities of high-end equipment manufacturing enterprises in Sichuan. Therefore, it is imperative to build a scientific evaluation indicator system of innovation ability for high-end equipment manufacturing industry in Sichuan Province! For this indicator system, scholars have carried out in-depth studies. He Zhengchu, Pan Hongyu, Deng Ying, and Xia Zhilun (2016) constructed evaluation indicator systems of technological innovation capability for China's high-end equipment manufacturing industry by using four primary indicators such as technological innovation input and technological innovation output, and nine secondary indicators such as R & D funds and patent applications. Based on these evaluation indicator systems, technological innovation capacity between 2004 and 2014 were analyzed and evaluated on China's six categories of high-end equipment manufacturing industry such as general equipment manufacturing and special equipment manufacturing.<sup>[2]</sup> Mou Shaobo, Huang Lei and Tian min (2013) constructed the evaluation indicator system of open innovation ability for industrial clusters based on four dimensions of technology absorption ability, market ability, innovation culture and social capital, and constructed the evaluation model

of open innovation ability for industrial clusters through fuzzy synthetical evaluation.<sup>[3]</sup> Zhang Tieshan, Lv Yingyi, Zhou Hui, Song Wenfeng (2017) studied and put forward countermeasures to develop high-end equipment manufacturing industry in Beijing <sup>[4]</sup>; Lv Yongquan (2015) , through in-depth study, put forward countermeasures against the existing problems in China's high-end equipment manufacturing industry<sup>[5]</sup>. Ma Fayao, Mou Shaobo, Huang Lei (2015) put forward countermeasures to improve the open innovation ability of high-end equipment manufacturing industry after a deeper study on the factors influencing such innovation ability<sup>[6]</sup>. Although the above studies put forward some indicators and countermeasures against different research objectives, none of them has made a choice for those indicators or given weight of each indicator, which just leaves research spaces for this topic. Therefore, this paper plans to build the evaluation indicator system on innovation ability for high-end equipment manufacturing industry in Sichuan Province, which could provide references in evaluating high-end equipment manufacturing enterprises in Sichuan Province and cultivating their innovation abilities.

## 2 Construction and selection of the evaluation indicator system on innovation abilities of high-end equipment manufacturing industry in Sichuan Province

### 2.1 Construction of the evaluation indicator system on innovation abilities of high-end equipment manufacturing industry in Sichuan Province

Quantitative factors and qualitative factors will both affect innovation ability. Therefore, both of these two types of factors should be included in the index system. In order to build a more objective evaluating indicator system, this paper synthetically analyzes the major characteristics of high-end equipment manufacturing industry in Sichuan Province, and draws on the research results from literature <sup>[6-10]</sup>, based on which an indicator system has been constructed including four primary indicators, ten secondary indicators and twenty-five tertiary indicators, as shown in table 1.

Table 1 Evaluation indicator system of innovation abilities of high-end equipment manufacturing industry in Sichuan Province

Primary indicators	Secondary indicators	Tertiary indicators	Tertiary indicator Serial No.	Indicator types
Innovation investment ability	Innovation capital investment	Total R&D investment in the past 1 year	1	Quantitative
		Proportion of R&D investment in operating revenue in the past 1 year	2	Quantitative
	Innovative HR input	Number of R&D personnel	3	Quantitative
		Proportion of R&D personnel in total employees	4	Quantitative
		Proportion of personnel with master's degree or above in total R&D personnel	5	Quantitative
Innovation and cooperation ability	External R&D cooperation level	Total external R&D expenditure	6	Quantitative
		Proportion of external R&D expenditure in total R&D expenditure	7	Quantitative
	External HR exchange and	Number of external partners	8	Quantitative
		The ratio of external partner number to	9	Quantitative

	cooperation	employee number in the enterprise		
	Production, school and research cooperation level	Number of universities and research institutions that have signed cooperation agreements with enterprises	10	Quantitative
		Proportion of R&D funds to universities and research institutions in total external R&D expenditure of enterprises	11	Quantitative
Innovation management ability	Management system incentive innovation	Policies encouraging innovation	12	Qualitative
		Incentive policies for innovative achievements	13	Qualitative
	Brand innovation	Policies encouraging brand innovation	14	Qualitative
		Number of famous brands owned by the company	15	Quantitative
Innovation output capacity	Authorized patents(copyright) obtained from R&D investment of 1 million CNY	Number of invention patents obtained from R&D investment of 1 million CNY	16	Quantitative
		Number of design patents obtained from R&D investment of 1 million CNY	17	Quantitative
		Number of utility model patents obtained from R&D investment of 1 million CNY	18	Quantitative
		Number of copyrights, software copyrights, integrated circuit layout design rights and other authorizations obtained from R&D investment of 1 million CNY	19	Quantitative
	Award level of scientific and technological achievements	National level	20	Qualitative
		Provincial and ministerial level	21	Qualitative
		Municipal level	22	Qualitative
	Innovation value realization	The ratio of patent licensing and transfer revenue to sales revenue of new products	23	Quantitative
		Proportion of sales of new products, new processes and new services in total sales	24	Quantitative
		Growth rate of output value of new products and services	25	Quantitative

## 2.2 Selection of indicators evaluating innovation abilities of high-end equipment manufacturing industry in Sichuan Province

Expert interviewing method was used to ask for opinions from experts studying innovation ability. In this study, entrepreneurs engaged in high-end equipment hired by Business School of Chengdu Jincheng College and experts studying innovation ability in both Business School and Financial School were selected as the objects to be consulted. According to the Expert Consultation and Survey Scale (see Appendix), experts were invited to grade each single indicator based on its relevance or importance to the topic: 1, 2, 3, 4 and 5 respectively represent extremely unimportant, relatively unimportant, general, relatively important and very important, and experts were also invited to propose on how to improve the evaluation indicator system.

30 Expert Consultation and Survey Scales were issued, among which 29 were effectively recovered. The effective recovery rate is 96.7%. The mean value of the score of each single indicator shows the concentration of experts' opinions in the consultation. The higher the mean value, the more important for each indicator to the topic.

Tertiary Indicator s No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Expert 1	2	2	2	2	1	2	2	2	3	3	3	4	4	4	4	5	3	4	3	1	2	2	1	4	2
Expert 2	5	4	4	5	4	4	5	5	5	4	4	5	5	5	5	4	5	4	4	4	3	4	4	5	4
Expert 3	5	4	4	4	4	4	4	4	4	3	4	5	5	5	4	5	5	4	5	4	4	4	4	4	4
Expert 4	5	4	4	3	4	4	3	4	4	4	5	5	4	3	4	4	3	4	4	4	4	4	4	4	4
Expert 5	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	4	4	4	5	4	4	4	4	5	4
Expert 6	4	4	5	4	5	4	4	5	5	5	5	5	5	5	4	4	4	4	5	4	4	4	5	5	4
Expert 7	5	4	4	4	5	4	4	4	5	4	4	4	5	4	4	4	5	5	5	4	4	4	4	5	5
Expert 8	5	4	4	4	5	3	4	5	4	3	4	5	4	3	4	5	3	3	4	4	3	4	5	4	3
Expert 9	5	5	5	5	5	5	5	4	4	3	3	5	5	5	5	4	4	4	4	4	4	4	4	4	4
Expert 10	4	3	4	4	4	3	4	3	5	4	5	5	5	4	4	5	5	4	3	4	4	4	4	5	4
Expert 11	5	5	4	4	4	4	4	4	4	3	3	4	4	4	4	3	3	3	4	4	4	4	4	5	4
Expert 12	5	5	4	3	3	5	5	4	4	3	3	5	5	3	1	5	4	4	5	5	4	3	4	4	4
Expert 13	4	4	4	4	4	5	5	4	4	4	5	5	5	5	5	3	3	4	4	4	4	3	4	4	4
Expert 14	5	5	5	5	5	5	5	4	3	5	5	5	5	5	5	5	5	5	5	5	4	4	5	4	4
Expert 15	4	3	4	5	5	3	3	4	4	5	4	4	5	4	4	3	3	3	4	2	2	2	4	4	3
Expert 16	5	4	5	5	4	5	4	4	4	5	5	5	5	5	5	3	3	3	3	4	4	4	4	4	4
Expert 17	4	4	4	3	3	4	4	3	3	4	4	5	5	5	4	4	4	4	4	4	4	4	5	5	4
Expert 18	4	4	4	4	4	5	4	4	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Expert 19	4	4	4	4	4	4	3	4	3	2	2	4	4	3	3	5	2	5	5	4	4	4	3	2	4
Expert 20	4	5	3	4	4	3	4	3	3	4	4	5	4	4	4	5	4	5	5	5	5	4	4	4	4
Expert 21	5	4	4	2	3	4	3	4	2	3	3	5	4	4	2	4	4	5	5	4	4	4	4	4	4
Expert 22	5	4	5	4	4	4	3	3	4	3	3	5	5	5	4	5	4	5	5	4	4	4	4	4	4
Expert 23	5	4	5	4	4	4	3	3	4	5	3	5	5	5	5	3	5	3	4	4	5	5	4	4	4
Expert 24	5	3	5	4	4	4	4	3	3	5	4	4	4	4	1	3	3	4	3	4	4	4	3	4	4
Expert 25	4	5	4	4	4	4	2	3	4	4	4	5	5	4	3	3	2	4	4	4	3	3	4	4	4
Expert 26	4	3	3	4	3	3	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4
Expert 27	4	4	3	3	4	3	3	3	3	3	3	4	4	4	4	3	3	3	3	3	3	3	3	3	4
Expert 28	4	5	4	5	5	2	3	1	1	4	3	3	4	3	3	3	2	2	4	4	4	4	4	4	3
Expert 29	4	4	3	2	2	3	3	3	3	4	4	4	4	4	3	4	3	4	5	4	4	3	3	3	3
Mean Value	4.41	4.03	4.03	3.86	3.93	3.83	3.72	3.66	3.69	3.9	3.86	4.59	4.55	4.21	3.83	4	3.66	3.93	4.21	3.86	3.79	3.76	3.86	4.14	3.83
Variance	0.47	0.53	0.53	0.77	0.85	0.72	0.71	0.81	0.86	0.74	0.69	0.32	0.26	0.53	1.15	0.64	0.88	0.57	0.53	0.55	0.46	0.48	0.55	0.48	0.29

According to the data in the table above, the mean value of the scores of the tertiary indicators with serial numbers of 4, 5, 6, 7, 8, 9, 10, 11, 15, 17, 18, 20, 21, 22, 23 and 25 is less than 4, which should be eliminated as they are between the general and relatively important; The scores of tertiary indicators with serial numbers of 1, 2, 3, 12, 13, 14, 16, 19 and 24 are larger than 4, which should be retained as they are between relatively important and very important, and. A number of experts proposed that the primary indicator of innovation cooperation and its related secondary indicators should be deleted due to their very limited impact on enterprises' innovation abilities of the high-end equipment manufacturing industry. After careful consideration, the author accepted the experts' suggestions and removed the primary indicator of innovation cooperation and its corresponding secondary and tertiary indicators. Besides, some experts thought that the indicator of the number of R&D personnel was rather too general as this number only reflected the investment scale of self-innovation personnel but failed to clearly reflect its investment intensity. After consideration, the author changed this indicator into full-time equivalent of R&D personnel, which refers to the number of R&D personnel converted by workload. Screened with the above measures, the indicator system is shown in Table 2.

Table 2 evaluation indicator system of innovation ability of high-end equipment manufacturing industry in Sichuan Province after screening

Primary indicators	Secondary indicators	Tertiary indicators
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Innovation input	Innovation capital investment	Total R&D investment in the past 1 year
		Proportion of R&D investment in operating revenue in the past 1 year
	Innovation HR input	Full time equivalent of R&D personnel
Innovation management	Management system incentive innovation	Policies encouraging innovation
	Brand innovation	Incentive policies for innovative achievements
Innovation output	Authorized patents(copyright) obtained from R&D investment of 1 million CNY	Number of invention patents obtained from R&D investment of 1 million yuan
		Number of copyrights, software copyrights, integrated circuit layout design rights and other authorizations obtained from R&D investment of 1 million yuan
	Innovation value realization	Proportion of sales of new products, new processes and new services in total sales

### 2.3 Determination of indicator weight

In this paper, order relation analysis is used to determine the weight of each indicator<sup>[11]</sup>. To facilitate the calculation of the weight, tertiary indicators are referred to as A1 – A9, as is shown in Table 3

Table 3 Tertiary indicators

Tertiary indicators	A <sub>1</sub> Total R&D investment in the past 1 year
	A <sub>2</sub> Proportion of R&D investment in operating revenue in the past 1 year
	A <sub>3</sub> Full time equivalent of R&D personnel
	A <sub>4</sub> Policies encouraging innovation
	A <sub>5</sub> Incentive policies for innovative achievements
	A <sub>6</sub> Policies encouraging brand innovation
	A <sub>7</sub> Number of invention patents obtained from R&D investment of 1 million yuan
	A <sub>8</sub> Number of copyrights, software copyrights, integrated circuit layout design rights and other authorizations obtained from R&D investment of 1 million yuan
	A <sub>9</sub> Proportion of sales of new products, new processes and new services in total sales

(1) Experts selecting. For this paper, six experts with different professional backgrounds were selected, among which three were experts in high-end equipment manufacturing research and three were in innovation network research, who assess the weight of each innovation ability evaluation indicator for high-end equipment manufacturing industry.

(2) Order relation arrangement and value-assignment. First, the 6 experts ranked the importance of each indicator in order. If the importance of evaluation indicator A<sub>u</sub> is greater than (or not less than) A<sub>v</sub>, it is recorded as A<sub>u</sub> f A<sub>v</sub>. Second, the 6 experts were asked to measure the importance between indicators A<sub>m</sub>-A<sub>m-1</sub> through 9 scales: rational judgements of  $\chi_{m-1} / \chi_m$ , the ratio of the importance degree of the evaluation indicators A<sub>m-1</sub> and A<sub>m</sub> by relevant experts, are set as follows:

$$\chi_{m-1} / \chi_m = R_m, \quad m=2, 3, 4, 5, 6, 7, 8, 9$$

$R_m$  assignment reference table is shown in Table 4.

Table 4  $R_m$  assignment reference table <sup>[11]</sup>

$R_m$ assignment	Meaning
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1.0	Indicator $A_{m-1}$ has the same importance as indicator $A_m$
1.2	Indicator $A_{m-1}$ is slightly more important than indicator $A_m$
1.4	Indicator $A_{m-1}$ is obviously more important than indicator $A_m$
1.6	Indicator $A_{m-1}$ is strongly more important than indicator $A_m$
1.1, 1.3, 1.5 and 1.7 stand for the intermediate situation of adjacent comparison judgment	

The 6 experts rank the importance of each indicator and assign values to  $R_m$ , the importance degree of two adjacent indicators in  $A_1 - A_9$  according to table 4. The results are shown in Table 5

Table 5 Experts' assignment to  $R_m$  and their ranking of evaluation indicators of innovation ability for high-end equipment manufacturing industry in Sichuan Province

Experts	Order relation	R2	R3	R4	R5	R6	R7	R8	R9
Expert 1	$A_1 f A_3 f A_2 f A_6 f A_5 f A_4 f A_8 f A_7 f A_9$	1.1	1.2	1.3	1.2	1.2	1.1	1.3	1.2
Expert 2	$A_1 f A_2 f A_3 f A_6 f A_5 f A_7 f A_8 f A_4 f A_9$	1.1	1.2	1.3	1.1	1.1	1.2	1.1	1.2
Expert 3	$A_3 f A_1 f A_2 f A_5 f A_6 f A_7 f A_4 f A_9 f A_8$	1.2	1.1	1.2	1.1	1.3	1.1	1.1	1.1
Expert 4	$A_3 f A_1 f A_2 f A_4 f A_5 f A_7 f A_6 f A_8 f A_9$	1.2	1.2	1.3	1.2	1.3	1.2	1.2	1.1
Expert 5	$A_1 f A_3 f A_2 f A_4 f A_6 f A_5 f A_7 f A_8 f A_9$	1.1	1.2	1.2	1.1	1.1	1.3	1.1	1.3
Expert 6	$A_1 f A_3 f A_2 f A_6 f A_4 f A_5 f A_9 f A_7 f A_8$	1.2	1.1	1.3	1.2	1.2	1.3	1.1	1.3

(3) Calculation of the weight of each indicator

To calculate the weight value of indicator  $A_u$  <sup>[11]</sup>  $\chi_u (u = 1,2,3, \dots, 9)$ , the calculation formula is as following:

$$\chi_9 = (1 + \sum_{m=2}^9 \prod_{u=m}^9 R_u)^{-1}$$

$$\chi_{m-1} = R_m \chi_m, (m = 9,8,7,6,5,4,3,2)$$

Base on the above formula, indicator weight values are calculated and reordered according to  $A_1 - A_9$ , as shown in Table 6.

Table 6 Weight of each indicator

Indicators	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
$A_1$	0.199	0.187	0.157	0.18	0.185	0.21
$A_2$	0.151	0.17	0.143	0.15	0.14	0.159
$A_3$	0.181	0.142	0.188	0.216	0.168	0.175
$A_4$	0.081	0.068	0.075	0.115	0.117	0.102
$A_5$	0.097	0.099	0.119	0.096	0.096	0.085
$A_6$	0.116	0.109	0.108	0.062	0.106	0.122
$A_7$	0.056	0.09	0.083	0.074	0.074	0.059
$A_8$	0.073	0.075	0.062	0.052	0.068	0.045
$A_9$	0.047	0.057	0.068	0.047	0.052	0.065

Averaging the weight of each indicator calculated from the indicator ranking by different experts, we get the final weight of each tertiary indicator:

$$\chi = (0.186, 0.152, 0.178, 0.093, 0.098, 0.103, 0.072, 0.062, 0.056)$$

Substitute the above calculation results into table 2, and calculate the weights of secondary and primary indicators. The results are shown in Table 7.

Table 7 Evaluation indicator system weight assignment of innovation ability of high-end equipment manufacturing industry in Sichuan Province

Primary indicators	Primary indicator weight assignment	Secondary indicators	Secondary indicator weight assignment	Tertiary indicators	Tertiary indicator assignment by G1 method
Innovation input	0.516	Innovation capital investment	0.338	Total R&D investment in the past 1 year	0.186
				Proportion of R&D investment in operating revenue in the past 1 year	0.152
		Innovation HR input	0.178	Full time equivalent of R&D personnel	0.178
Innovation management	0.294	Management system incentive innovation	0.191	Policies encouraging innovation	0.093
				Incentive policies for innovative achievements	0.098
		Brand innovation	0.103	Policies encouraging brand innovation	0.103
Innovation output	0.19	Authorized patents(copyright) obtained from R&D investment of 1 million CNY	0.134	1 Number of invention patents obtained from R&D investment of 1 million yuan	0.072
				Number of copyrights, software copyrights, integrated circuit layout design rights and other authorizations obtained from R&D investment of 1 million yuan	0.062
		Innovation value realization	0.056	Proportion of sales of new products, new processes and new services in total sales	0.056

### 3. Conclusions and suggestions

Table 7, shows that the innovation capability of high-end equipment manufacturing industry in Sichuan Province is most affected by innovation investment, accounting for 51.6%; ranking No. 2 is innovation management, accounting for 29.4%; ranking the last is innovation output, accounting for 19%. Therefore, in order to improve the innovation ability of high-end equipment manufacturing enterprises in Sichuan Province, innovation investment should first of all be increased, including innovation capital investment and innovation HR investment, that is to increase the number and proportion of computer-controlled automatic manufacturing equipment and relevant R&D personnel in order to improve the ability of high-end equipment industry on intelligent manufacturing; meanwhile, products should be further innovated and new technologies, such as Internet of Things, cloud computing and artificial intelligence etc., should also be widely applied in new products in order to increase their level of networking, informationization and intellectualization which will help increase their market competitiveness. Secondly, innovation management should be implemented and the whole process of enterprise innovation should be included in process management. We should not only encourage innovation in the management system, making a system to encourage innovation and tolerate failures, to reward individuals and their teams for achieving innovation results, but also implement brand innovation strategy, formulate policies to encourage brand innovation and improve



the environment for enterprises' internal governance. Finally, we should actively apply for and obtain patents (copyrights), improve the proportion of sales of new products, new processes and new services in the total sales, and further enhance the company's ability of continuous innovation.

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## Appendix: questionnaire of expert consultation and investigation - scoring of primarily selected indicators of innovation ability of high-end equipment manufacturing industry in Sichuan Province

Distinguished experts and scholars:

Hello! We are teachers of Chengdu Jincheng College. Now we are doing a research on the innovation ability of high-end equipment manufacturing industry in Sichuan Province. Through comprehensively analyzing the main characteristics of high-end equipment manufacturing industry in Sichuan Province, and drawing on the research results of relevant literature, we preliminarily formed the following evaluation indicator system of innovation ability of high-end equipment manufacturing industry in Sichuan Province. Please grade each single indicator according to its relevance or importance. 1, 2, 3, 4 and 5 respectively represents extremely unimportant, relatively unimportant, general, relatively important and very important. If necessary, please put forward your suggestions for further improvement of the evaluation indicator system.

This is only an academic survey. Thank you very much for your cooperation!

Primary indicators	Secondary indicators	Tertiary indicators	unimportant extremely unimportant	unimportant relatively unimportant	general	important relatively important	important very important	Score
			1	2	3	4	5	
Innovation investment ability	Innovation capital investment	Total R&D investment in the past 1 year						
		Proportion of R&D investment in operating revenue in the past 1 year						
	Innovative HR input	Number of R&D personnel						
		Proportion of R&D personnel in total employees						
		Proportion of personnel with master's degree or above in total R&D personnel						
	Innovation and cooperation ability	External R&D cooperation level	Total external R&D expenditure					
Proportion of external R&D expenditure in total R&D expenditure								

	External HR exchange and cooperation	Number of external partners						
		The ratio of external partner number to employee number in the enterprise						
	Production, school and research cooperation level	Number of universities and research institutions that have signed cooperation agreements with enterprises						
		Proportion of R&D funds to universities and research institutions in total external R&D expenditure of enterprises						
Innovation management ability	Management system incentive innovation	Policies encouraging innovation						
		Incentive policies for innovative achievements						
	Brand innovation	Policies encouraging brand innovation						
		Number of famous brands owned by the company						
Innovation output capacity	Authorized patents (copyright) obtained from R&D investment of 1 million CNY	Number of invention patents obtained from R&D investment of 1 million CNY						
		Number of design patents obtained from R&D investment of 1 million CNY						
		Number of utility model patents						

		obtained from R&D investment of 1 million CNY						
		Number of copyrights, software copyrights, integrated circuit layout design rights and other authorizations obtained from R&D investment of 1 million CNY						
Award level of scientific and technological achievements		National level						
		Provincial and ministerial level						
		Municipal level						
Innovation value realization		The ratio of patent licensing and transfer revenue to sales revenue of new products						
		Proportion of sales of new products, new processes and new services in total sales						
		Growth rate of output value of new products and services						