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Research Article EAI.EU

Input-Output Performance Evaluation of Science and Technology Enterprises Based on DEA Model

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Abstract

INTRODUCTION: For enterprises, the results of performance evaluation will be affected by the selected input and output factors, so the indicators of the evaluation system should be representative and characteristic, and the evaluation method should be reasonable.

OBJECTIVES: According to the characteristics of science and technology industry, this paper establishes the performance evaluation index system, and the evaluation model of the input-output performance for the science and technology enterprises.

METHODS: With the evaluation model, this paper empirically analyses the evaluation index data of 30 science and technology enterprises in recent 3 years, and verifies the effectiveness of the selection of management performance evaluation index of science and technology enterprises.

RESULTS: Finally, according to the empirical analysis results of the evaluation model.

CONCLUSION: This paper puts forward some countermeasures to improve the business performance of science and technology enterprises.

Keywords: performance evaluation; input-output ratio; technical efficiency

Received on 12 October 2023, accepted on 19 February, published on 20 February 2024

doi: 10.4108/ew.4131

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1. Introduction

The enterprises of science and technology obtain profits with relevant technologies, using software and hardware design, development, technical services, wholesale trade and other business models. Business performance is the core content of enterprise management. The good development of science and technology enterprises is also inseparable from business performance. The correct evaluation of enterprise performance can provide decision basis for managers and direction for enterprise reform, and the scientific evaluation can maintain a good development ecology of enterprises. Enterprise performance evaluation can be understood as the evaluation of the benefits and management mode obtained by the enterprise in a certain period of operation. Apigian, Charles H. et al. (2005) studied the enterprise performance by using structural equation method and found that the close integration of strategic decision with enterprise business process and technology can enhance its market position [1]. Teck-Yong Eng (2008) showed that the advantage of product technology level can improve the performance of enterprises through the study of sample data and can be used to customize user engagement and expansion [2]. Fang-Mei Tseng (2009) added the index of non-financial data latitude into the financial index, established an evaluation index system from five aspects of operation, innovation, customers and suppliers, financial index and competition, and established a comprehensive evaluation of enterprise performance [3]. Kallunki J P, et al. (2011) pointed out that the business performance evaluation system is a branch of the internal management of a company in their research on business performance evaluation, and it can balance the operating conditions and financial development of an enterprise with this system, which played an important role in the management of an enterprise [4]. Zheng Cailing (2015) made assumptions through relevant studies, improved the original DEA method on the basis of the assumptions, built the sum virtual unit, determined the unique common weight, and established the rating and ranking research on enterprise performance [5]. Meza L A (2016) used DEA model to evaluate the operational efficiency of an airline. By studying the sample data of effective DUS and the effective input-output target value, which could help enterprises optimize operation efficiency [6]. Jang H et al. (2016) selected 49 sample data to study the R&D efficiency of enterprises by using DEA-Malmquist method and found that the efficiency of the overall sample enterprises was in a declining state [7]. Xue Zhuozhi (2017) proposed valuable suggestions for enterprise performance evaluation by refining the index system from the perspective of input-output for each level of enterprise input index and combining data envelopment analysis and hierarchical analysis when establishing enterprise input index [8]. Xue Jun (2018) selected sample data of more than 30 enterprises, established a financial analysis model, ranked the sample companies according to the model analysis results, and put forward relevant suggestions for the business performance of the technology industry [9]. Zhang Fengzheng (2018) compared the evaluation methods of science and technology enterprises with those of other traditional enterprises, established the quantitative methods and improved the evaluation model of science and technology enterprises better [10]. The evaluation methods used by previous scholars often take the predetermined goal as the evaluation standard, which excludes the continuity of input and output. This inevitably leads to the evaluator's misjudgment of the real development of the situation, hinders the development and renewal of the evaluation object's behavior, and restricts the creative play of the evaluation object.

Based on the above research results, most researchers did not have the characteristics of performance evaluation of science and technology enterprises, nor did they correctly select performance evaluation indicators of science and technology enterprises. In addition, although a few literatures put forward the performance evaluation indicators of enterprise input-output, there is a lack of effective evaluation methods.

2. Theoretical

The purpose of the evaluation system is to improve the level of enterprise management. At the same time, accurate assessment can reduce the relevant business risks of enterprises. The research of evaluation system provides the basis for managers to make decisions, and it is conducive to finding the deficiencies and defects in enterprise management, so that resources can be more rationally controlled and efficiently utilized.

The DEA model uses optimization as a tool, takes the weight coefficients of multi-index input and multi-index output as decision variables, and evaluates in the sense of optimization, avoiding the determination of index weight coefficients in the sense of statistical average, which has inherent objectivity. Especially when dealing with the correlation and mutual restriction between input and output in science and technology enterprises, DEA method is effective in evaluating the scale of multi-input and multi-output production departments.

In this paper, DEA (Data Envelopment Analysis) method is selected to evaluate the business performance of science and technology enterprises [11], which has the following advantages:

(1) For the business performance of enterprises with more input and more output, the DEA method does not need to consider the functional relationship before input and output and is not affected by some factors.

(2) The Decision-Making unit (DMU) is not affected by the input-output data unit and does not need to process the indicator data unit separately. It is that percentage data and non-percentage data can be selected when selecting the data because the unit of the data does not have to be considered except for negative numbers, the format of the data can be arbitrarily selected, not

restricted by the data format [12].

(3) When selecting indicators, it is not necessary to set the weights of indicators in advance, so as to exclude subjective interference factors.

DEA method can measure the efficiency value of enterprise input and output to a certain extent, and can obtain the effectiveness of each DMU, which is widely used because of its unique advantages. The two most widely used models are CCR model and BCC model. In many studies, all decision units are based on the premise that scale efficiency does not change, and the BCC model takes this into account, and can well calculate scale efficiency, pure technical efficiency and comprehensive efficiency. In order to better study the return to scale and efficiency value of science and technology enterprises [13], this paper establishes a mathematical model to conduct a quantitative evaluation of the input-output performance of science and technology enterprises. The specific steps are as follows [14]:

Step1: Establish the objectives that need to be evaluated. Before the establishment of the model, the evaluation objective of the model should be preliminarily established according to the object of evaluation.

Step2: Establish the decision unit. In this paper, the data of 30 science and technology enterprises in recent 3 years is selected as the research object, which accords with the foundation of the model.

Step3: Establish the input index and output index. From the perspective of input and output, this paper selects the growth rate of net profit and total profit as the output index.

Step4: Establish the evaluation model. After selecting the evaluation index, this paper establishes the management performance evaluation model of science and technology enterprises by quantitative technology.

Step5: Analyse and evaluate the results.

DEA method is only the relative efficiency evaluation of DMU, but not the absolute efficiency evaluation. Therefore, DEA cannot completely replace the traditional ratio analysis method to analyze absolute efficiency. Moreover, the DEA method cannot measure the condition of negative output. Linear model assumptions simplify DEA analysis, but the output is the premise of linear programming solution, if the output is negative, it cannot be measured under this method. Therefore, when using this method, users need to promote its strengths and avoid its weaknesses.

3. Model

1. Select evaluation indicators

Compared with the research results of previous scholars, DEA method puts forward the improvement direction for the inefficient DMU. By analyzing the relaxation variables, DEA method can further understand the utilization status of non-efficient DMU resources, and propose the direction and size of improvement for its non-efficient resources, so as to provide a way for decision-makers to improve efficiency.

In this paper, when establishing the system of the management performance evaluation for the science and technology enterprises, the selection indicators of "input" and "output" is mainly based on the following: the science and technology enterprises cannot develop without the science and technology, and technical ability is their core competitiveness. With strong scientific and technological capabilities, the science and technology enterprises can create better products and achieve good performance [15]. At the same time, the science and technology enterprises also shoulder social responsibilities such as promoting science and technology and increasing workers' income [16]. It is conducive to the stability and long-term operation of business strategy that the science and technology enterprises fulfil certain social responsibilities well. In the selection of investment indicators of scientific research ability, this paper preliminarily selects four indicators: research input, scientific research team, product brand and enterprise scale. In the selection of social responsibility input indicators, this paper preliminarily selects indicators: workers' income, tax payment according to law, repayment ability and employment promotion [17]. Both research input and social responsibility have a positive effect on the financial performance of the science and technology enterprises [18]. According to the previous research, the index system of the performance evaluation for the scientific research enterprises is preliminarily established, as shown in Table 1.

Table 1. Evaluation index system primary election

target layer	criteria layer	indicator layer
input index	research capacity	research team research input enterprise scale

		product brand
	social	worker's income
	responsibility	pay taxes
		solvency
		employment
output		management ability
indicator	profitability	sales revenue
		asset income
	sustainability	market share
		technological innovation

For the technology enterprises, whether the growth is good or not, it is directly related to attract investors well. When products and services have been unable to meet the needs of consumers, the technology enterprises will face the risk of being eliminated. Therefore, when evaluating the science and technology enterprises, it should not only consider their own profitability, but also focus on the sustainable development of the science and technology enterprises [20]. In the selection of output indicators, this paper will take into account not only profitability, but also the sustainability of enterprises.

2. Analyse evaluation indicators

(1) Research input. The science and technology enterprises mainly rely on the support of technology. The development of an enterprise is good or bad, and a large extent depends on the technical level of the enterprise. The development of technology requires a lot of financial support. The higher the level of technological investment of the enterprise has the higher the input cost. This shows that the higher the degree of technological investment, the enterprise will have the higher the cost of scientific research investment.

(2) Scientific research team. The core competitiveness of the science and technology industry is the technical ability. The development of technical ability needs a large amount of financial support, but also it needs a large number of talents with a high-level scientific research team in order to promote the continuous progress of science and technology and design better products, occupy the market share. So that it promotes the business performance of the science and technology enterprises.

(3) Workers' income. In the technology as the core of the science and technology enterprises, staff resources are the important wealth of the enterprise. Technology enterprises assume a more important position in the social responsibility to employees. For the intense competition in the technology industry, the employee stress and work intensity are generally higher than other industries. Therefore, the total salary expenditure is chosen as the social responsibility of enterprises to employees. The higher the income of the workers, the enterprise has the higher the degree of social responsibility to the employees.

(4) Product brand. A good product brand will greatly contribute to the improvement of corporate awareness and competitiveness. This kind of improvement does not come from the investment of human, material and financial resources, but this shows that the enterprise has the intangible cultural force of "brand".

(5) Solvency. First of all, repayment ability reflects the maximum amount of debt that an enterprise can bear, and it is the main factor that an enterprise has to consider in the process of raising funds. Secondly, the stronger the solvency, it indicates that the enterprise has a better reputation and the significance of value, the stronger the degree of trust by investors. Solvency can indicate the income and risk of an enterprise, and enable relevant stakeholders to identify whether benefits are available and whether debts can be repaid.

(6) Enterprise scale. Enterprise scale, social responsibility and product are the planning of enterprise development and they need effective strategic guidance. The scale of the enterprise does not only affect the economic strength and market share of the enterprise, but also it affects the management level of the enterprise and the working state of the employees.

(7) Promoting employment. Providing social employment rate is also the master of determining the future direction of social development of enterprises. At the same time, providing more employment opportunities is the social responsibility of entrepreneurs and their enterprises for social development, and it also includes the high expectations of society for enterprises.

(8) Pay taxes according to law. Enterprises pay taxes according to law in addition to contributing tax revenue to the state, and that also solves the employment of the masses, alleviates the pressure on the government, and that ensures the overall stability of society. All these reflect the responsibility that enterprises should bear for social and economic development.

(9) Net profit. The same as other industries, the ultimate goal is to obtain the corresponding benefits of science and technology enterprises, and the profitability is an important indicator to measure the profitability of an enterprise. Especially

in the science and technology enterprises, the profitability has been attached importance by relevant stakeholders. In this paper, economic income is chosen to represent the profitability of the enterprise. The higher the net profit, the enterprise has the stronger the profitability and the better the operating efficiency.

(10) Sustainability. In order to cope with the increasingly accelerated change and competition, the science and technology enterprises should not only accelerate the speed of value innovation in strategy, but also they are good at learning and continuous learning. The science and technology enterprises may help to improve the ability of all aspects through continuous learning. At all levels, those are conducive to research and exploration of new methods to find new market opportunities. And those are conducive to achieve the value of the market parties leap, and affect the development and change of the entire industry.

3. Establish evaluation model

According to the characteristics of input-output performance evaluation of the science and technology enterprises [21], this paper assumes that the return to scale of decision-making unit DMU is fixed, and defines the optimal evaluation index A.

$$A = Max \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{n=1}^{N}\beta_{ij}Q_{in}}{\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\alpha_{im}P_{in}} \tag{1}$$

$$t.\quad \frac{\sum_{i=1}^{I}\sum_{n=1}^{N}\beta_i Q_{in}}{\sum_{i=1}^{I}\sum_{n=1}^{N}\alpha_i P_{in}} \le 1, i = 1,2,\cdots,I;\ n = 1,2,\cdots,N;\ m = 1,2,\cdots,M$$

$$\alpha_i \ge 0, \beta_i \ge 0,\ \forall n, i. \tag{2}$$

P_{in} is the t th input of the i th producer in the previous year under the m-type input influencing factors. Q_{in} is the m th output of the i th producer in the previous year under the j-type output influence factors. α_i is the statistical change coefficient of input of the i th producer in the previous year. βi is the statistical change coefficient of output of the i th producer in the previous year. According to the duality principle in linear programming, the above formula can be transformed into the expression of the dual problem.

$$Min\ A \tag{3}$$

$$st.\quad \sum_{i=1}^{I}\sum_{n=1}^{N}\beta_i Q_{in} \le A\sum_{i=1}^{I}\sum_{n=1}^{N}Q_{in} \tag{4}$$

$$\sum_{i=1}^{I}\sum_{n=1}^{N}\alpha_i P_{in} \le A\sum_{i=1}^{I}\sum_{n=1}^{N}P_{in} \tag{5}$$

In this paper, relaxation variable B, residual variable C and infinite small quantity δ are introduced. If fixed and constant returns to scale are converted into variable returns to scale, this paper builds an input industry evaluation model.

$$Min\ A - \delta(\sum_{i=1}^{I}B_i + \sum_{i=1}^{I}C_i) \tag{6}$$

$$st.\ \sum_{i=1}^{I}\sum_{n=1}^{N}\alpha_i P_{in} + \sum_{i=1}^{I}B_i = A\sum_{i=1}^{I}\sum_{n=1}^{N}P_{in}$$

$$\sum_{i=1}^{I}\sum_{n=1}^{N}\beta_i Q_{in} - C = \sum_{i=1}^{I}\sum_{n=1}^{N}Q_{in} \tag{7}$$

Based on the influence factors of M input and J output, this paper also considers the influence of environmental variable φ_in on relaxation variable B and residual variable C, and further optimizes the evaluation results of production input.

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{n=1}^{N}\beta_{ij}\,Q_{ijn} = \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\{\alpha_{im}\,P_{in} + [\max(\varphi_{in}B - \varphi_{in}C)] + [max\,Q_{in} - Q_{in}]\} \tag{8}$$

4. Results and Discussion

In the actual data collection and analysis application process, DEA method must be completed with the use of analysis tools. At present, many scholars use DEA to collect and analyze data in two ways: one is to use DEA analysis software directly, the other is to complete the calculation by compiling DEA programs.

This paper also chooses the enterprise operation efficiency and technical efficiency as the external environment indicators in order to improve the evaluation effect in addition to establishing the evaluation system.

This paper selects the input and output index data of 30 science and technology enterprises in the past three years as the research object in order to verify the input-output evaluation model of the science and technology enterprises, and analyzes the technical efficiency and operational efficiency of these enterprises, as shown in the Table 2.

(1) Operating efficiency. For the science methods to adapt to external environmental factors, the enterprises make use of the advantages of environmental factors to give full play to their own characteristics, so as to improve their business performance. At the same time, they should make good use of the entire market environment to match the changes in the enterprise and external

environment [22].

(2) Technical efficiency. With the development of market economy, the overall external environment is also constantly changing, which has different impacts on the technical efficiency of the overall science and technology industry at different stages. In the entire external environment, the science and technology industry began to appear a series of resource competition, such as talent competition, innovative technology competition, so that the technical efficiency changes with the change of the environment [23].

For the input-output evaluation indicators initially selected, this paper analyzes the results of relevant indicators according to the above data, as shown in the Table 3.

In the evaluation research, if the variable is positive value, it will affect the increase of input, which can be understood as expanding the variable redundancy of input, and then it can be understood as causing a negative impact, and it means that it is an unfriendly environmental factor. On the contrary, if the coefficient is negative value, it means that the input is reduced, and the corresponding input variable redundancy will be reduced, which will have a positive impact. This paper examines the influence of environmental factors on each input index, and adjusts the input value of the previous year by eliminating environmental factors and random errors. From the overall effect, there are some significant relationships between the preliminary selected input variables, such as research input, research team, product brand, operating scale, worker income, tax payment, repayment ability, and employment promotion, and various environmental factors. This shows that it is meaningful to the initial selection of input indicators. Using the model of the input-output evaluation, this paper further analyzes the test values of relevant indicators, as shown in Table 4.

Table 2. Efficiency value from 2020 to 2022

enterprise code	operating efficiency			technical efficiency		
	2020	2021	2022	2020	20201	2022
1	0.74	0.69	0.40	0.76	0.70	0.44
2	0.88	0.99	0.99	0.99	0.99	0.99
3	0.99	0.99	0.72	0.99	0.99	0.99
4	0.99	0.67	0.75	0.99	0.69	0.79
5	0.30	0.31	0.33	0.30	0.30	0.33
6	0.84	0.50	0.53	0.80	0.59	0.53
7	0.60	0.95	0.51	0.61	0.98	0.66
8	0.90	0.99	0.99	0.93	0.99	0.99
9	0.99	0.99	0.99	0.99	0.99	0.99
10	0.74	0.50	0.39	0.75	0.54	0.41
11	0.99	0.66	0.82	0.99	0.75	0.82
12	0.40	0.46	0.69	0.40	0.45	0.68
13	0.51	0.40	0.30	0.51	0.45	0.31
14	0.39	0.26	0.25	0.40	0.30	0.28
15	0.53	0.99	0.49	0.53	0.99	0.50
16	0.56	0.56	0.47	0.63	0.55	0.61
17	0.57	0.66	0.70	0.57	0.63	0.71
18	0.87	0.99	0.99	0.98	0.99	0.99
19	0.43	0.56	0.57	0.50	0.59	0.61
20	0.71	0.80	0.99	0.72	0.89	0.99
21	0.99	0.99	0.69	0.99	0.99	0.70
22	0.30	0.50	0.32	0.33	0.51	0.31

23	0.99	0.99	0.99	0.99	0.99	0.99
24	0.99	0.66	0.59	0.99	0.69	0.62
25	0.85	0.84	0.62	0.97	0.84	0.62
26	0.99	0.99	0.92	0.99	0.99	0.93
27	0.99	0.99	0.95	0.99	0.99	0.99
28	0.99	0.99	0.99	0.99	0.99	0.99
29	0.91	0.99	0.98	0.99	0.99	0.99
30	0.39	0.43	0.75	0.66	0.44	0.77

Table 3. Index analysis from 2020 to 2022

		research input	team building	Workers' income	Employment promotion	repaying capability
2020	Convention factors	-1.20	168.00	-26789.25	7.01	-0.29
	policy support	1.60	3.10	0.10	-0.10	0.18
	business indicators	-0.99	-12.00	34.00	-0.38	0.27
	macro economy	-1.10	5.30	6.04	-0.61	-0.31
	scale economy	0.80	1.40	3.00	-1.50	-0.59
2021	Convention factors	-12000.28	-934.00	-26100.25	-6.00	-0.20
	policy support	0.94	0.10	1.99	0.01	0.01
	business indicators	-170.00	-25.99	-110.06	0.01	0.02
	macro economy	0.01	0.10	0.75	-0.90	0.01
	scale economy	-2.78	0.01	-0.99	-0.98	-0.99
2022	Convention factors	-10001.30	-83.04	-28011.00	-128.00	-0.60
	policy support	0.99	0.10	2.00	0.01	0.01
	business indicators	-330.00	-29.92	-160.00	0.45	0.02
	macro economy	0.47	0.19	0.99	0.01	-0.01
	scale economy	-0.01	0.01	-0.01	-0.19	-0.98

Table 4. Test value from 2020 to 2022

	research input	team building	workers' income	employment	repaying capability
2020	90.10	94.00	85.09	86.10	83.80
2021	91.00	93.80	86.04	84.90	84.90
2022	90.68	92.10	85.56	85.05	84.20

When analyzing the environmental factors in the past three years, this paper finds that the value of important indicators is basically above 90.00 with the evaluation model and the impact of random factors and management factors. These results indicate that evaluation indicators have particularly significant impacts on management factors, such as scientific research investment, research input, team building, product brand and enterprise scale, and reflecting the importance of investment indicators for the development of the science and technology enterprises. In addition, the value of the evaluation indicators is basically above 80.00 through the data analysis of 30 science and technology enterprises, such as worker income, tax payment, repayment ability, and employment promotion. This reflects the importance of social responsibility to the output of the science and technology enterprises [24].

(1) Policy support. From the data, policy support has a significant positive relationship with slack variables such as research input and research team. It is not significant of the three input factors of policy support, repayment ability and the improvement of social employment rate. And this indicates that these input factors will be indirectly affected by the environmental factors of policy support along with the annual operation of the science and technology enterprises.

(2) Management ability. As a good business manager, he or she is to raise his or her spiritual realm to a new height, responsible for the employees, responsible for the enterprise. Managers need to unleash the potential and creativity of their employees, and give them a sense of accomplishment they have never had before. At the same time, managers also need to constantly improve the enterprise system and enterprise culture. This can make the excellent employees unwilling to leave the enterprise, and create greater value for the enterprise.

(3) Macroeconomic conditions. Macroeconomic conditions represent the level of development of a region. A high level of development of a region, if the enterprises want to develop, it is necessary to increase efforts with the improvement of economic level, improve the existing business model, increase investment to attract talents with increasing the more costs of research and development. At the same time, when macroeconomic conditions is the stable of the economy, the enterprises will have more funds to invest in other aspects.

(4) Management system. With the expansion of the scale and the perfection of the management system, the internal resources of the enterprise can be well utilized. If the enterprise wants to achieve a certain market position in operation, it must be supported by the optimal enterprise management system.

5. Conclusion

This paper studies the important index system that affects the input-output performance of the science and technology enterprises based on the evaluation model.

(1) Policy support is negatively correlated with the performance of the science and technology enterprises. There may be information asymmetry and corruption between the government and enterprises, which may cause enterprise resources to fail to meet the real demand, resulting in the distortion of market resource allocation. Similarly, it will also adversely affect the effectiveness of policy support for the imperfect supervision of the use of enterprise resources.

(2) Management ability is positively correlated with the performance of the science and technology enterprises. For the science and technology enterprises with fierce competition, the development trend of managers' ability is consistent with the business performance of enterprises. The excellent managers can better supervise the business activities of enterprises, form a supervision system, avoid buck-passing and reduce incentive costs.

(3) Macroeconomic conditions are positively correlated with the performance of the science and technology enterprises, but the significance is not obvious. The development of regional economy has opened up gaps in investment resources, human resources, scientific and technological strength and other aspects of science and technology, which may have a certain impact on the business activities of the science and technology enterprises.

(4) Operating scale is positively correlated with the performance of the science and technology enterprises. If the science and technology enterprises want to obtain technological innovation in a certain field, it needs the support of the large-scale enterprises, and the small enterprises will be subject to relevant constraints in the process of project development. Enterprise scale can represent a certain strength of the enterprise, and the large-scale enterprises can better control funds, strong financial background, conducive to the operation and development of enterprises, while these are able to resist certain risks.

In short, compared with traditional performance evaluation methods, the DEA method proposed in this paper has more advantages and it is more intuitive in finding the gap between scientific and technological enterprises. And by combining parameter analysis methods, it can find the factors affecting efficiency and other characteristics. Therefore, for the efficiency evaluation of science and technology enterprises, this paper will further explore the model and method suitable for the efficiency evaluation of science and technology enterprises in various countries. At the same time, compared with the efficiency of the same type of business units, this study improves the overall efficiency of the industry and promotes the progress of the industry.

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