IOSR Journal of Economics and Finance (IOSR-JEF)
e-ISSN: 2321-5933, p-ISSN: 2321-5925.Volume 11, Issue 2 Ser. VII (Mar – Apr 2020), PP 21-27
www.iosrjournals.org

Research on the Impact of Research and Development Input on Investment Efficiency in DEA

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Abstract: *In the blueprint of the future manufacturing industry, the innovation is the most important for enterprises. However, the lack of innovation and efficient investment has an impact on the rapid development of Chinese advanced manufacturing industry. In this paper, the Data Envelopment Analysis (DEA) is used to calculate the investment efficiency of listed companies. A-share Manufacturing Listed Companies in 2015-2018 are selected as the researched object. The results reveal the relationship between research and development (R&D) input and investment efficiency. Namely, it is a U-shaped trend between R&D input and investment efficiency; and the lower the investment efficiency is, the lower the enterprise performance is. It will provide a reference for the investment behavior of enterprises.*

Keywords: *R&D input, Investment efficiency, Enterprise performance, DEA*

Date of Submission: 15-04-2020 Date of Acceptance: 30-04-2020

I. Introduction

As is known, if a country wants to accelerate the pace of industrialization, it must regard the development of manufacturing industry as the foundation of a strong country. On the one hand, it is to cope with a new round of technological and industrial changes in the world. On the other hand, the shadow of the financial crisis in 2008 has led countries around the world to formulate a strategy of "re-industrialization" with the revitalization of manufacturing as the core, supplemented by legislation. However, in China, it is faced with the problems of insufficient high-end products, and excessive middle and low-end products, which forces it to urgently need industrial transformation and upgrading. First of all, the current situation of overcapacity needs to be urgently changed, and how to improve the efficiency of investment to optimize the allocation of enterprise resources needs to be solved urgently. Besides, the insufficient supply of high-end products highlights the imbalance of China's industrial structure, which increases the demand for innovation activities. In response, the Chinese central government has successively put forward various strategic plans such as "Mass Innovation", "Made in China 2025" and "Supply-side Structural Reform (SSSR)", and has issued a series of policy measures aimed at encouraging enterprise innovation, improving the current situation of enterprises, and promoting the long-term development of enterprises.

At present, many scholars have studied the relationship between R&D input and enterprise performance and enterprise value from different perspectives, but there is little research on the relationship between R&D input and enterprise investment efficiency. So, will the R&D input affect the investment efficiency? In macro economy, investment efficiency is used to measure the efficiency of resource allocation of the whole society. In enterprises, investment efficiency is closely related to the resource allocation of capital. So, what is the relationship between investment efficiency and corporate performance?

Based on this, this paper selects A-share Manufacturing Listed Companies in 2015-2018 as the research object, uses the data envelopment analysis (DEA) BBC (Banker,Charner and Cooper) model to test the relationship between R&D input and investment efficiency from the perspective of input-output. The purpose of this paper is to improve the efficiency of enterprise investment, provide the basis for enterprise managers to make investment decisions, and have a certain degree of innovation in design, selection, research, evaluation and other aspects.

II. Literature Review

As early as the 1960s and 1970s, foreign scholars have studied the relationship between R&D input and enterprise performance, and most of them adopt empirical research method. Isabel Estrada et al. (2019) analyzed the experience data of 911 Spanish manufacturing companies from 2007 to 2014, and proved that the bad cooperation between enterprises intensifies the bad competition of investors and cause the negative impact of corporate profitability with the increasing R&D input[1]. Coad et al. (2019) used machine learning community and ICA analysis method to call the largest R&D investor database in the world. The results show that the policy of increasing private R&D can better target the growth of sales and employment, and then improve the

performance of enterprises[2]. Kim et al. (2019) analyzed R&D input and investment efficiency through the national database of South Korea, which showed that R&D input had limited impact on economic growth, and the proportion of R&D input in total capital investment should be adjusted[3].

In contrast, China's research on R&D input is backward, and most of the R&D activities imitate foreign technologies. China's research base is also weak, which restricts the research. In summary, there are two aspects of research: the first is linear research. In this field, Zheng et al.(2018) concluded that R&D input of GEM listed enterprises is significantly positively correlated with current enterprise performance[4]. Zhang et al. (2018) proposed that the implementation of executive compensation incentive in China's GEM enterprises can improve enterprise performance and promote enterprises to increase R&D input. It is proved that R&D input plays an intermediary role in the process of executive compensation incentive influencing enterprise performance[5]. Moreover, Wang et al. (2017) adopted the micro data set of enterprises in Haidian Science and Technology Park of Zhongguancun, obtained the conclusion that sustained R&D input will have a "negative-positive-negative" nonlinear impact on technological innovation performance through empirical test[6].

According to the above, there is no consistent conclusion on the impact of R&D input on enterprise performance in the existing literature. Compared with previous studies, the significance of this study concludes two aspects: On the one hand, the investment efficiency from the perspective of input-output is measured, and the non-linear relationship between R&D input and investment efficiency and its characteristics is studied. On the other hand, the investment level of manufacturing listed companies is considered, the investment shortage and investment transition is calculated, the investment efficiency according to the previous experience is analyzed. It will provide decision-making reference for manufacturing enterprises.

III. Research Hypothesis

New economic growth theory, namely endogenous growth theory, holds that technological innovation is the internal core driving force of economic growth and technological innovation is the source of economic growth. Paul M.Romer, a representative, first used the theory of "learning by doing" to establish an endogenous economic growth model in 1990, which incorporated knowledge technology into the economic growth model. Romer puts forward that technological progress is the core of economic growth, and maintaining long-term economic growth will ultimately promote the continuous iterative renewal of new technologies[7]. These new technologies come from the investment of enterprises, and innovate in the R&D Department of enterprises. Enterprises will have the intellectual property of these new technologies-patents in continuous attempts. After obtaining the patent and under the protection of the patent, the enterprise can carry out monopoly production and sales of new technology, and finally obtain excess profits.

However, the R&D activity itself will not increase the investment output, and the promotion effect for the enterprise mainly depends on the success of R&D and the effect on the enterprise after the success of R&D. In addition, R&D activities are uncertain, experimental and time-consuming. At the beginning of R&D investment, there will be a certain waste of resources. Even if R&D is successful, enterprises need time to cooperate with the invested capital to effectively absorb or transform their achievements into innovative products. Therefore, the profits of enterprises will be restrained to a certain extent at the beginning of R&D investment. With the increase of R&D input and the accumulation of knowledge, and overcome the technical difficulties, the core technology will gradually mature and combine with the relevant innovation activities. This makes the effect of R&D activities on the investment output of enterprises gradually clear, and it shows a growing trend. Such growth is not achieved overnight, but gradually. When the growth accumulates to a certain extent, it will play the largest role in the input-output of enterprises, and it can really improve the investment efficiency of enterprises, and then promote the development of enterprises. Based on the above analysis, hypothesis 1 is proposed.

H1: It is a U-shaped trend between R&D input and investment efficiency.

As one of the most important activities of an enterprise, investment activities affect the decision-making of the enterprise. Whether the leaders of an enterprise can choose value-added investment through analysis for the enterprise will not only affect the performance of the enterprise but also affect the interests of stakeholders. However, correct and effective investment activities often create value for enterprises. But the investment with complete efficiency can only appear in the market environment with no risk and ideal moral hazard. In the existing market environment, it is often difficult for enterprise leaders to grasp the degree of investment, so there will be an insufficient investment and excessive investment.

Under investment often leads to the dilemma of the enterprise, which causes the enterprise to have higher financial leverage, and the stakeholders cannot enjoy the benefits and give up the investment in the project, thus losing the value of the company. Over investment may lead to the blind pursuit of self-interest and neglect of enterprise interest due to information asymmetry, principal-agent and other issues. It makes leaders make high-risk decisions, reduces the efficiency of capital allocation, and reduces the company's performance. Whether it is under investment or over investment, it will lead to the loss of enterprises. Therefore, hypothesis 2 is

proposed.
H2: The lower the investment efficiency is, the lower the enterprise performance is.

1.1 Research Design(Sample selection and data source)

This paper collects the relevant data of Chinese A-share listed companies in the manufacturing industry in 2015-2018, and conducts the following processing: (1) Remove the listed companies delisted in 2015-2018, and remove the listed companies marked ST and * ST; (2) Remove the listed companies with missing financial performance indicators and control variable indicators. (3) As the dependent variable in this paper lags one year behind the independent variable, the independent variable comes from 2015-2017, and the dependent variable comes from 2016-2018. Considering the survey period of sample enterprises is 3 years, 324 sample data and 324 observations are used. The data of this paper comes from the annual reports of listed companies published by cninfo.com and the CSMAR database. This paper reviews and supplements some financial data and Sina Finance's annual report to ensure that the information is complete and accurate.

1.2 Variable design and model construction

(1) Explained variable (investment efficiency)

Many pieces of literature that use Richardson model to measure investment efficiency from the perspective of resource allocation. This paper will measure investment efficiency from the perspective of input-output. The most commonly used methods in efficiency evaluation are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). DEA can overcome the subjective factors by using the principle of linear programming, and the efficiency result measured by DEA is more robust than that of SFA. Besides, the DEA method can be divided into the Charnes, Cooper and Rhodes (CCR) model and Banker,Charner and Cooper (BBC) model[8]. The former is the most widely used model in the DEA method, which is applied to the relative effectiveness evaluation of decision-making units (DMU) under the premise of constant returns to scale. The latter is used to evaluate the relative effectiveness of DMU under the premise of variable returns to scale. BCCmodel breaks through the assumption that the scale return of CCR is constant, and can measure pure technical efficiency and scale efficiency, which is more practical and comprehensive. Therefore, this paper selects the BCC model with non-Archimedes infinitesimal to evaluate the comprehensive investment efficiency, which is shown in Formula 1.

$$Min[\theta - \varepsilon(e^T s^- + \hat{e}^T s^+)]$$

$$s.t. \quad \sum_{j=1}^{n} x_j \lambda_j - s^- = \theta x_0 \qquad \forall \theta,\ \lambda_j \geq 0, j = 1,\ldots,n;\ s^- \geq 0. \qquad (1)$$

$$\sum_{j=1}^{n} y_j \lambda_j - s^+ = y_0 \qquad \lambda_j \geq 0, j = 1,\ldots,n;\ s^+ \geq 0. \qquad (2)$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad \lambda_j \geq 0, j = 1,\ldots,n \qquad (3)$$

Where $\varepsilon > 0$ is the non-Archimedean infinitesimal, s^+ is the slack variable of output, s^- is the redundant variable of input, j is the number of decision-making units, and λ is the weight value.

In the establishment of the investment efficiency index system, this paper combines the characteristics of the manufacturing industry, and research divides input variables into short-term input and long-term input, and output variables into operating income and net profit. The main basis is as follows: the products generated by R&D input are conducive to the promotion of enterprise value. One part is the intangible assets such as patent and non-patent technology, while the other part is the formation of tangible physical assets. In the production and operation activities of manufacturing enterprises, R&D input has a certain lag effect. When selecting input variables, it should cover all aspects of human, material and capital investment in production and operation.

Specifically, it should include fixed assets such as long-term factory buildings, machinery and equipment, and intangible assets such as patent and non-patent technology, as well as cost input such as short-term material and labor costs, and employee compensation, depreciation and amortization needed for organization and management. The necessary expenses incurred by the products put into the market are also included, such as freight and miscellaneous expenses, publicity expenses, sales expenses and subsequent maintenance expenses; as well as the necessary capital to support the operation of the enterprise, such as: inventory turnover, direct working capital of turnover accounts. The output indicators reflect the operating results of the above-mentioned enterprises, which are expressed in terms of operating income and net profit. Finally, the input-output index

system is obtained. It is as shown in Table 1.

Table 1. Evaluation index system of investment efficiency

Input variables	Long-term	Net value of fixed assets and intangible assets
	Short-term	Operating cost, management expense, sales expense, production and operating working capital
Output variables		Operating income, and net profit

In this paper, all negative values are taken as absolute values because the variables required by DEA are non-negative. In this research, the software of DEAP2.1 is used to calculate the investment efficiency value of 108 DMUs in 2015-2017. The final comprehensive efficiency value is 1, and the smaller the efficiency value is, the lower the investment efficiency is.

(2) Variable explanation (R&D investment)

As an important part of enterprise innovation technology, R&D input is divided into the absolute index and relative index when selecting index. The absolute index generally takes the natural logarithm of R&D expenditure, and the relative index mainly includes R&D expenditure / total assets and R&D expenditure / operating revenue. Compared with the absolute index, the relative index can reflect the relative situation of each element and the internal structure of the enterprise, and more reflect the comparability among enterprises. Therefore, this paper chooses the relative index. In the relative index, the ratio of R&D expenditure to total assets is selected as the measurement index to avoid the endogenous problem of the denominator.

The return on assets (ROA) financial index can be used to measure the reporting rate of the invested capital of an enterprise. It generally reflects the profit rate generated by the common capital of shareholders and creditors. It is different from the return on equity (ROE), and its fundamental difference lies in the view of creditor's rights and financial leverage. To understand a company's real operational capability, it should be analyzed in combination with ROE and ROA. For a company, if the ROA is at a good level and its debt level is within a reasonable range, then the roe level of the company should also be good, which shows that the company operates well as a whole. On the contrary, if the ROA is at a low level and there are many debts, while the ROE is at a high level, it is easy to mislead investors to judge the profitability of the company. For this reason, this paper selects ROA as the evaluation index of enterprise performance at the macro level.

(3) Control variables

To get the evaluable results, this paper refers to the relevant research from Jiang (2016) in the selection of control variables. It considers the controlling variables which may affect investment efficiency from three aspects of enterprise-scale, capital structure and growth. Besides, it also controls the shareholding ratio of the management, and the investment efficiency of the shareholding ratio with equity incentive is higher. ROA reflects the performance level of enterprises to a certain extent, so it also includes this indicator. The specific variable definitions are shown in Table 2.

Table 2. Definition of variables

Variable Name	Variable Symbol	Variable Declaration
Investment efficiency	E	Using BCC model of DEA method to calculate the comprehensive efficiency value
R&D input	RD	Natural logarithm of R&D expenditure
Shareholding ratio of management	Mar	Ratio of the number of shares held by the management to the total number of shares
Capital structure	Lev	Asset liability ratio = Total Liabilities / Total Assets
Growth	Growth	Growth rate of main business
Return on assets	ROA	Net profit / Total Assets

(4) Model

To verify the hypothesis, this paper gradually adds control variables and analyzes the primary and secondary terms of independent variables. Considering that R&D input has a certain lag, this paper deals with the independent variable RD lag for one period, and establishes the R&D input and investment efficiency model as follows:

$$E_{i,t} = \beta_0 + \beta_1 RD_{i,t-1} + \beta_2 RD^2{}_{i,t-1} + \beta_3 Mar_{i,t} + \beta_4 Lev_{i,t} + \beta_5 Growth_{i,t} + \beta_6 ROA_{i,t} \quad (4)$$

2 Empirical Analysis

(1) Descriptive analysis

The descriptive statistical results of each variable are shown in Table 3, which shows that the average investment efficiency of the manufacturing industry is 0.513, while the minimum value is only 0.017. It can be found that there are great differences and it shows that the overall level of the manufacturing industry needs to be improved. The average value of R&D input is 0.022, which indicates the China gradually attaches importance to R&D investment. Also, it can find that the manufacturing enterprises take active actions, but the R&D intensity is still low, and the distribution is uneven.

On the other hand, the shareholding ratio of company management is 16.4%, the median is 4%, and the maximum is 99.8%. This shows that the two-level equity differentiation is serious, most of the company's top executives are likely to have an insufficient shareholding ratio, and the equity is relatively concentrated; the average value of asset-liability ratio is close to the median, which indicates that the distribution is relatively uniform.

In terms of growth performance, the maximum reached 467.031%. This shows that the development of enterprises is rapid, which may be related to a series of welfare policies. The growth of enterprises is good, and there is a big difference between the lowest value and the highest value of ROA, which indicates that different enterprises have different performance in decision-making.

Table 3. Descriptive statistical results

Variable	Mean	Median	St.dev	Minimum	Maximum
E	0.513	0.448	0.105	0.017	1.000
RD	0.022	0.014	0.001	0.000	0.195
Mar	0.164	0.040	0.021	0.238	0.998
Lev	49.893	52.040	441.122	3.016	163.559
Growth	18.205	11.437	2447.875	-2.002	467.031
ROA	0.346	0.022	3.336	-2.002	24.657

(2) Correlation analysis

The correlation analysis between variables is shown in Table 4. The results show that ROA and investment efficiency are negatively correlated, which indicates that certain investment will affect the benefit of the enterprise in the current period, which may be related to the decision-makers of the enterprise. The correlation coefficient between investment efficiency and R&D input is negative, the Pearson correlation coefficient is 0.3, which is only significant at the level of 10%, and the correlation is poor. Besides, the shareholding ratio of management has a weak positive correlation with ROA and a negative correlation with investment efficiency and R&D investment.

Moreover, the capital structure is negatively correlated with ROA and R&D investment, which may indicate that R&D activities are as unique as innovation activities. Such uniqueness will affect the debt ratio of the company, and then the enterprises with more R&D investment. It makes enterprises more willing to carry out internal equity financing rather than debt financing, which has little correlation with investment income and negative correlation with management shareholding ratio, which may indicate that enterprises with concentrated equity have serious two-level differentiation and may affect the performance of enterprises.

From the perspective of the growth performance of the enterprise, the growth of the enterprise cannot be separated from the investment of the company, and a good investment decision is conducive to the sound development of the enterprise.

Table 4. Correlation coefficient test between variables

Variable	ROA	E	RD	Mar	Lev	Growth
ROA	1					
E	-0.046	1				
RD	-0.002	-0.132*	1			
Mar	0.09	-0.084	-0.023	1		
Lev	-0.038	0.057	-0.108	-0.114*	1	
Growth	-0.067	0.094	-0.06	-0.026	-0.042	1

* Significant at 10%

(3) Regression analysis

The hierarchical regression results are shown in Table 5, in which model 1 and model 2 are gradually added with control variables and independent variables, model 3 is added with ROA based on model 2, and model 4 is added with the second term of R&D input based on model 3. It can be found that the DW values of all models are between 0-2, there is no autocorrelation, and the models are significant.

From Table 5, it can also be seen that the shareholding ratio of the management is negatively related to investment efficiency, and the standardized correlation coefficient is -0.075. The asset-liability ratio, the growth of the company and the investment efficiency are positively correlated, the correlation coefficient is 0.038, 0.084. The relationship between R&D input and investment efficiency is negatively correlated, and its standardization coefficient is -1.636. Based on model 3, R2 has an upward trend after adjustment.

Table 5. Hierarchical regression results

Variable	Dependent variable: E							
	Model 1		Model 2		Model 3		Model 4	
	β	*T*	*β*	*T*	*β*	*T*	*β*	*T*
Mar	-0.075	-1.348	-0.080	-1.441	-0.077	-1.384	-0.075	-1.348
Lev	0.052	0.932	0.038	0.674	0.037	0.654	0.038	0.674
Growth	0.094	1.696	0.086	1.554	0.084	1.509	0.084	1.517
RD			-0.125	-2.249	-0.125	-2.251	-0.211	-1.667
ROA					-0.033	-0.590	-0.035	-0.632
RD2							0.096	0.755
F	1.962		2.754		2.269		1.983	
R2	0.018		0.033		0.034		0.036	

From the regression results, the square term of R&D input is positively related to investment efficiency, and the standardization coefficient is 0.72, which is consistent with the hypothesis of H1, that is, R&D input and investment efficiency show a U-shaped trend. Besides, the ROA of the company affects the investment efficiency of the company. The ROA is negatively related to the investment efficiency, and the standardized coefficient is -0.035, which is consistent with the descriptive results in Table 3 and conforms to the hypothesis of H2. To further verify the reliability of the above research results, this paper will further verify the relationship between each factor to get better results.

(4) Robustness analysis

To further test whether the conclusion of the sample is valid under other conditions, this paper conducts a robustness test from three perspectives.

Data: adjust according to different classification standards. In the paper, ROA may be related to RD, Lev, Growth, and Mar. Therefore, it takes ROA as the control variable to verify with the original results, and check whether the test results are still significant.

Variables: select other variables to replace to see if they have any impact on the hypothesis. In this paper, the natural logarithm of R&D input is selected for regression analysis, and ROE is used as an alternative of the dependent variable for the regression test.

Measurement method: select another measurement method to verify the results. In this paper, the Chi-square test is used to test the relationship between variables. Besides, the main regression results of the above stability tests are consistent with the above empirical results, which shows the robustness of this paper.

IV. Conclusion

In conclusion, this research selects 324 sample data of Chinese A-share Manufacturing Listed Companies from 2015 to 2018, and uses the perspective of input-output to verify the relationship between R&D input and investment efficiency, as well as the relationship between investment efficiency and enterprise performance. The main conclusions are as follows: first, there is a U-shaped relationship between R&D input and enterprise efficiency, that is, R&D input will inhibit the investment efficiency of enterprises with the increase of investment amount, and only when the investment accumulation to a certain extent will it plays a role in promoting the investment efficiency of enterprises. Second, investment efficiency is negatively correlated with enterprise performance, that is, over investment and under investment exist in the enterprise, but the decision-maker of the enterprise has not noticed it, which affects the value of the enterprise.

Based on the research of this paper, the following suggestions are proposed to provide a reference for improving enterprise performance. Firstly, R&D input has a lag promoting effect on enterprise performance. In reality, however, it is often difficult to measure the value range of R&D investment, which requires each enterprise to do according to its development trajectory and to measure R&D input experimentally rather than blindly taking actions and blind investment.

Secondly, investment also means risk. Decision-makers should not only pay attention to net profit and net assets but also understand the risk situation of the enterprise itself. For the sake of a virtuous cycle of the enterprise, they should reduce short-sighted behavior, establish a good internal control system, do a good job in supervision, strengthen risk awareness, so as to ensure the authenticity and reliability of information sources. Besides, science and technology are the first productivity, enterprises should actively carry out innovation activities so that R&D products can create more value for the company after successful R&D.

Finally, the government should take effective measures to stimulate the innovation of enterprises to alleviate the worries of enterprises. In practice, it suggests that the government introduce various preferential policies and protect the patent technology and intellectual property rights of enterprises, so as to encourage enterprises to be brave in innovation, promote the transformation and upgrading of manufacturing enterprises, and boost the grand plan of "Made in China 2025".

Data Availability

The [EXECL TYPE] data used to support the findings of this study were supplied by WIND DATABASE.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Social Foundation of China under Grant No.16CGL070. And the authors would like to thank the reviewer for their insightful comments. addressing them has improved the quality of the paper.

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Hua-Ping Wu,etal. "Research on the Impact of Research and Development Input on Investment Efficiency in DEA." *IOSR Journal of Economics and Finance (IOSR-JEF),* 11(2), 2020, pp. 21-27.