

Research on the Innovation Efficiency of Artificial Intelligence Enterprise Based on DEA Method

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Abstract. This paper uses DEA method to evaluate innovation efficiency of 40 typical artificial intelligence enterprise in our country, which inputs element as human (research and development personnel accounted for the ratio of the total number of employees) and capital (the ratio of R&D and business revenue), and which output elements as technology (patent number and the sum of the number of software copyright) and economic (operating profit margin). Combining with the evaluation results, the paper analyzed comprehensive efficiency, pure technical efficiency and scale efficiency, return to scale and input redundancy of 40 artificial intelligence enterprise representative in our country. The results show that comprehensive efficiency is low, scale efficiency and pure technical efficiency are not high, and some enterprises have factor redundancy. It is innovative in industry research for selecting 40 enterprises and collecting relevant data of 40 enterprises by using enterprise statements, statistical yearbook, government bulletin and peer, and to conduct research with DEA method.

Progress of Artificial Intelligence Research

Recently, a large number of artificial intelligence have sprung up, our country enterprise, the technology leader in their respective fields or the market share leader, start-up enterprises such as Han Wu Ji, Shen Jian S&T, Tan Yun Intelligence, ChuMenWenWen, Shang Tang S&T, Di Ping Xian and so on. Competitive advantage has been formed in field of smart chip, computer vision, speech recognition, intelligent life solutions and medical gene and other fields. In addition, IFLYTEK, the most famous voice recognition company. Apple, Google, Microsoft, Amazon, Facebook, Tencent and Alibaba are the world's top seven companies by market value. In addition to apple doing both hardware and software, the other six are doing software and services, all of which are involved in the artificial intelligence industry. Among the top 20 companies with the highest market value in the world, 7 companies are financial enterprises, ExxonMobil is an energy company. According to the data of Venture Scanner in 2017, the total number of start-ups specializing in artificial intelligence worldwide reached 2542. The United States has about 110, China has about 600, and the rest of the world has about 800. Among China's AI startups, there are 146 computer vision and image companies, 125 intelligent robot companies and 92 natural language processing companies. China and the United States account for two-thirds of the total number of artificial intelligence start-ups in the world, and have a clear advantage in the industry, far ahead of other countries, and become leaders in the artificial intelligence industry.

Generally speaking, the United States is in a leading position in the world. The United States leads in the field of artificial intelligence and is the most active country in artificial intelligence field investment and financing. The amount of financing exceeds that of all other countries in the world. The financing scale of China's artificial intelligence enterprises shows an explosive growth trend. Up to 2018, 767 investment cases concerning artificial intelligence have taken place in China's venture capital institutions, and the cumulative financing amount has climbed to 63.5 billion yuan, accounting for 33.1 percent of the total global financing. There are only 31 self-driving/assisted driving enterprises in China, but the amount of financing is the third in China with 10.7 billion yuan, accounting for 18%. Natural language processing, 12.2 billion yuan, accounting for 19%. Computer

vision and image, the amount of financing for 14.3 billion yuan, accounting for 23%. A large number of domestic start-ups and start-ups have access to a variety of financing, a variety of investment capital and investors are increasing. Chinese enterprises engaged in artificial intelligence need to improve the efficiency of innovation as soon as possible.

Literature Review of Artificial Intelligence

Artificial intelligence will be widely used in medical care, education, travel, security, finance, intelligent security, intelligent wear, intelligent home and other fields. According to the publication trend of Elsevier's artificial intelligence papers, from 2012-2016, among the top 100 research institutions and universities in the world in terms of the number of citation of artificial intelligence papers, the United States ranked first with 30, China ranked second with 15, and Japan ranked 64th in the world with only one university of Tokyo. Less than 30 per cent of the three authoritative international conferences on artificial intelligence have been approved by experts before attending them. The international conference of the American association for artificial intelligence is the most authoritative, and the number of publications in the United States and China has surged in the past three years. In 2005, 326 (48.4%) were published by American universities and enterprises, with the highest proportion, followed by 138 (20.5%) in China. The two countries account for about 70 percent of the total. The United States has five of the top ten institutions and universities in the world to publish related papers, and China has two, with the Chinese Academy of Sciences ranking third in the world. France, Singapore and Canada each have one.

According to the published literature in China, the research on artificial intelligence mainly focuses on the application of artificial intelligence, ethical discussion and discussion on the possibility of artificial intelligence replacing human beings. In the application research of artificial intelligence, Cao Yangtian [1] analyzed the application of artificial intelligence control technology in the fields of electrical product optimization design, fault prediction and diagnosis, control and protection. Jiang Yan, Hu Tao and Yang Ning [2] analyzed the positive effects of expert system, artificial neural network and data mining on the improvement of medical level. Chen Duanduan [3] built a complete system of artificial intelligence in the field of art communication: collecting data, quantifying data, mining data, establishing models, understanding and matching art information and audience needs, and accurate communication. In terms of ethical discussion, Li Xiuquan [4] discussed the rights, codes of conduct and education of robots from the perspective of technology security, data collection, cloud computing and privacy in the process of knowledge extraction. Xiong Qi [5] evaluated the copyright of artificial intelligence from the aspects of rights identification and ownership. In terms of the substitution of artificial intelligence for human beings, Gao Qiqi and Li Huan [6] evaluated the possibility of artificial intelligence defeating human beings from the perspectives of self-learning, emotion and self-meaning. Wang Xiaoyang [7] constructed a new argument based on collective personal identity to prove that "producing a new intelligent machine that can respond in a similar way to human intelligence" is difficult to achieve. Existing researches on artificial intelligence mainly focus on qualitative researches on applied technologies and ethical norms, but lack quantitative empirical analysis. In view of this, this paper USES DEA to conduct empirical research on the technological innovation efficiency of artificial intelligence enterprises.

Innovation Efficiency of Artificial Intelligence

In 1978, the famous American operations research scientist Chsrnes et al. first proposed data Envelopment Analysis (DEA), which is an efficiency evaluation method based on the concept of relative validity. DEA algorithm takes each object to be evaluated as a Decision Making unit (DMU), and multiple Decision Making Units jointly constitute the evaluated group. By dividing the indicators into input indicators and output indicators, the efficiency and effectiveness of each Decision Making unit are determined by optimization operation with the weights of input and output indicators as variables. DEA method does not need to estimate the parameters of the

evaluation model in advance, effectively avoids the influence of subjective factors and reduces errors. Moreover, it is evaluated according to the conversion efficiency and is not affected by the size difference of the objects to be evaluated, which is conducive to horizontal comparison and relatively simple calculation. The above characteristics have unique advantages in evaluating the R&D performance of listed companies. Therefore, this paper chooses data envelopment analysis to study the R&D performance evaluation of listed companies in the artificial intelligence industry. The selected DEA model and its calculation process are as follows.

Based on previous indicators, this paper measured innovation input and innovation output of AI companies. Specific indicators are shown in table 1. This index system involves manpower input, capital input, technical output and economic output.

(1) Manpower input. As the implementer of enterprise innovation activities, R&D personnel directly participate in the technological innovation activities of enterprises, which represent the innovation potential of enterprises. In this paper, the ratio of R&D personnel to the total number of employees is used to measure the degree of human resources investment.

(2) Capital input. As a high-tech enterprise, the research and development activities of artificial intelligence enterprises are a long-term process that cannot be separated from the continuous capital investment of the enterprise. As for the measurement of research and development intensity, this paper adopts the current common indicator -- the ratio of research and development expenses to operating income.

(3) Technical output. Technical output is the output of research and development in the process of enterprise innovation, and is the direct embodiment of innovation results. It is expressed by the sum of the number of patents and the number of software copyright.

(4) Economic output. The ultimate goal of innovation activities of artificial intelligence enterprises is to obtain the commercial value brought by innovation results and improve economic benefits. Operating profit rate is the core of economic benefit indicators. In this paper, operating profit rate is taken as an important indicator of economic output of innovation activities.

Table 1. Evaluation Index System of Innovation Efficient of AI Enterprises

Primary index	Secondary index	Tertiary index	Calculation Method
Innovation input	Human capital invested	The proportion of R&D personnel	R&D personnel / the total number of employees in that year
	Fund invested	R&D intensity	R&D expenditure/revenue of the year
Innovation output	Technology product	The number of patents	The sum of the number of patents obtained by enterprises and the number of software Copyrights
	Economic output	Operating profit margin	Operating profit/current year operating income

The research and development input and output data of 40 representative artificial intelligence enterprises are selected in this paper. All the data are selected from the enterprise statements of information network. Considering that the research and development activities need a certain period from input to output, the lag period is 1 year, that is, the input data is 2017 and the output data is 2018.

Using the software DEAP2.1 and taking input as the guide, the efficiency operation results of 40 artificial intelligence enterprises are shown as follows: the comprehensive efficiency, technical efficiency and scale efficiency of Chinese artificial intelligence enterprises are all relatively low. There are 3 enterprises with the comprehensive efficiency at the forefront, 7 enterprises with effective technology and 3 enterprises with effective scale. Comprehensive efficiency, pure technical efficiency and scale efficiency of average 0.339, 0.495, 0.668; technology effective and ineffective company scale has four, ping an group, Hkust Xunfei, Cambrian, full of science and technology, in which the Cambrian and all the scale efficiency is far below the average level of science and technology, this rather than take the scale expansion, set up many branches, leading to the imperfection of the branch, personnel, capital, technology wasn't up to the rational allocation of each respect. The low comprehensive efficiency of these four companies is completely caused by

scale inefficiency. The enterprise scale can be adjusted according to the corresponding scale compensation. To be specific, PingAn group is in a state of constant return to scale and does not need to adjust its scale, but it has capital redundancy. Xunfei at Hkust and whole science and technology progressing scale stage, the scale inefficiency is caused by the small size, need to expand the scale of enterprise, Hkust fly no input redundancy, in terms of personnel and funds need to be further investment, the technology capital is redundant, need to strengthen the construction of scientific research team, in order to achieve effective scale state; Cambrian was in the stage of diminishing returns to scale. Among the enterprises with both pure technology and scale inefficiency, ZhongKe chuangda, ShangTang technology, GiAo aggregation, QiHan technology, JiaDu technology, MinLue data, Zebra intelligence, XiaoMa Intelligence, Go Out and ask, YunCong technology, these 10 enterprises have higher scale efficiency, but lower pure technical efficiency, which makes the overall efficiency lower. Existence capital redundant is the enterprise that scale returns increases more.

From the point of comprehensive efficiency, 40 artificial intelligence enterprise comprehensive efficiency mean just 0.339, only 14 comprehensive efficiency is greater than the average of listed companies, accounting for 35% of the total number of samples, it reflects the current in the low level of industry innovation performance of artificial intelligence, most of the enterprise personnel, capital investment not give full play to the role, the use of inputs as efficiency is low, firms not to maximize output. Baidu, Tencent and Hawaii are at the forefront of efficiency. Their comprehensive efficiency, pure technical efficiency and scale efficiency are all 1, and they are in the stage of constant scale reward. These enterprises have a long history of development, accumulated rich experience in technological innovation, and made full use of innovation resources. They not only surmounted the stage of increasing returns to scale, but also avoided falling into the stage of diminishing returns to scale, thus achieving the highest efficiency.

From the perspective of pure technical efficiency, the average of pure technical efficiency is 0.49, and 17 artificial intelligence enterprises are above the average level, accounting for 42.5% of the total sample. The mean of pure technical efficiency is higher than the comprehensive efficiency and lower than the scale efficiency. The pure technical efficiency of Baidu, Tencent, Hawaii, PingAn group, Iust, Cambrian and Quanzhi is 1, which reaches the efficiency frontier. Although the pure technical efficiency of Alibaba, Bgi, Sogou and JinDao group has not reached the frontier, the efficiency of these five enterprises is also relatively high, ranking among the top. They belong to the enterprise type with high technical efficiency, while the pure technical efficiency of other enterprises is relatively poor.

From the perspective of scale efficiency, the mean of scale efficiency is 0.66, and 19 enterprises are above the mean, accounting for 47.5% of the total sample. Baidu, Tencent and Hawaii are at the forefront of scale efficiency with a value of 1. The efficiency of Alibaba, Bgi, Cke Chuangda, YingPu technology, ShangTang technology, MingLue data, zebra-zhixing and ma zhixing are also very high. Scale efficiency is higher than pure technical efficiency in both average and number of enterprises.

From the perspective of scale return, most enterprises are in a state of increasing scale return and need to further increase their R&D investment. 32 enterprises are in the stage of increasing return to scale, accounting for 80% of the total. Three companies, ShangTang, Cambrian and horizon, are in the stage of diminishing returns to scale. Among the five enterprises with the same scale remuneration, there are not only Baidu, Tencent and Hawaii, which are the three frontier enterprises of comprehensive efficiency, but also ping a group with high pure technical efficiency and Cke Chuangda Company with high scale efficiency but other low efficiency. As China's artificial intelligence is in the initial stage and the input of factors is insufficient, each unit of input will increase the output accordingly. With the increase of input, the benefit will be better and better, which is the feature of increasing returns to scale.

From the perspective of investment redundancy, personnel redundancy is less, capital redundancy is more, and capital utilization efficiency needs to be improved. The redundancy mean of personnel input is 0.004, and the redundancy mean of capital input is 0.009. The redundancy mean of capital

is greater than the redundancy mean of personnel. After 40 years of reform and opening up, China's economy has grown in size with sufficient material wealth, especially the capital stock, which ranks among the top in the world. In the past five years, China has invested 2.69 billion yuan in the field of artificial intelligence, with a frequency of 691, involving computer vision, service robots, voice and natural language processing, intelligent medical care, intelligent driving and other fields. However, China is not a strong country in science and technology, and there are not enough scientific and technological talents, especially the number of sophisticated scientific and technological talents. Therefore, we need to strengthen the quality construction of scientific and technological talents.

Conclusions and Suggestions

By comparing the comprehensive efficiency, pure technical efficiency and scale efficiency of 40 representative listed artificial intelligence companies, as well as the redundancy of scale return investment, the following conclusions can be drawn.

The innovation performance of AI listed companies has a large internal gap with a low average level. The maximum value of innovation performance is 1, the minimum value is 0.07, and the average value is 0.339, indicating that the innovation level of artificial intelligence enterprises needs to be improved. The allocation of R&D resources of listed artificial intelligence companies is unreasonable and most of them are non-DEA effective, which indicates that the combination of R&D resources of these companies is not optimal. Investment redundancy is a common problem in these companies. The efficiency of personnel and capital utilization is low, resulting in a waste of resources.

According to the above conclusions, this paper believes that the innovation efficiency of China's listed artificial intelligence companies should be improved from three aspects: government, artificial intelligence industry and listed artificial intelligence companies:

The government should strengthen the support and guidance role for China's artificial intelligence industry. The government should formulate effective policies and measures to purify the innovation environment of artificial intelligence enterprises, protect enterprise patents, software copyright and other innovative achievements, and ensure the healthy development of artificial intelligence enterprises. Artificial intelligence is mainly divided into technical layer, application layer and basic layer. The technology layer includes general technology platforms of artificial intelligence (such as computer vision and images, natural language processing, and voice recognition), such as Apollo autonomous driving platform released by Baidu. Application layer includes artificial intelligence industry application solution, consumer terminal or service. The basic layer includes artificial intelligence chips, algorithms and data. Compared with the characteristics of the whole industry layout in the United States, China mainly focuses on the application side; in addition, there are only partial breakthroughs in the technical layer and the basic layer. Many universities in China have not specialized in artificial intelligence for a long time, while in the United States, the birthplace of artificial intelligence, major universities have specialized in artificial intelligence and research directions. Cameron University in the United States, for example, has a special robotics institute, which has more than 100 professors. The engine of the development of artificial intelligence, actually is two, capital and talent. Although the United States was ahead of China in both of these projects, for China, due to its large population and large number of science and engineering graduates, given the right industrial environment, they can quickly grow into talents in actual research and development. Support will be given to ai enterprises in terms of financial subsidies and tax relief, and venture capital investment in ai enterprises will be regulated. Meanwhile, Banks will be encouraged to lend money to ai enterprises, reduce financing costs of ai enterprises, improve capital utilization efficiency and reduce capital redundancy. From the two aspects of personnel and funds, solve the problem of unreasonable allocation of innovation investment and improve the innovation efficiency of artificial intelligence enterprises.

Artificial intelligence industry should actively absorb technical resources and human resources. Alliance, through the establishment of artificial intelligence production, carry out various forms of

cooperation between colleges and create enterprise incubation center, cultivate and improve the mechanism of the transformation of innovation achievements, at the same time, strengthen the cultivation of the talent with universities and research institutes mechanism, to introduce more innovative talents, improve the innovation efficiency of the entire enterprise of artificial intelligence. Scale advantage will bring great value to itself. China's booming Internet industry also makes the enterprise become a training center for artificial intelligence talents. With the boom of artificial intelligence, China's artificial intelligence start-ups have shown a trend of vigorous development, with groups of cutting-edge artificial intelligence enterprises growing rapidly, and nearly 80% of them are concentrated in first-tier cities such as Beijing, Shanghai, Guangzhou and Shenzhen. Artificial intelligence is a highly knowledge-intensive industry. Beijing's environment of talents, technology, industry and capital is better than that of other regions. In the future, the artificial intelligence industry will form a geographical layout with Beijing as the absolute core and Shanghai, Guangzhou and Shenzhen as the key first-tier cities.

We will comprehensively optimize the ratio of R&D personnel to funding in artificial intelligence enterprises, and improve the efficiency of R&D funds and the professional and technical level of R&D personnel. Artificial intelligence enterprises should reasonably spend the research and development results of the application of funds, science and technology development funds; By implementing equity incentive for core R&D personnel and their teams, the R&D personnel shall have the right to participate in the enterprise operation, the right to vote and the right to claim for earnings, align the interests of R&D personnel with the interests of the company, and improve the enthusiasm of R&D personnel for innovation activities. For R&D team, we should not only provide high salary, good welfare and other health measures, but also implement humanized management, respect and value talents, enhance the cohesion and attraction of R&D staff, and reduce staff turnover rate. At the same time, by taking high-efficiency companies in the industry as the benchmark, through the introduction of advanced technology, the production, management and management level of contributing enterprises, as well as the innovation efficiency, the overall innovation efficiency of the listed artificial intelligence companies will be improved.

In a word, we must start from the government, artificial intelligence industry and artificial intelligence enterprises three levels, take targeted improvement programs and measures to improve the status quo of innovation of artificial intelligence enterprises in China, improve the innovation efficiency of artificial intelligence enterprises, and promote the comprehensive and healthy development of artificial intelligence enterprises in China.

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