Abstract—This paper, beginning with the content of self-technological innovation and its capability, re-decomposes and defines the elements of enterprise self-technological innovation capability, and then sets up the evaluation index system of enterprise self-technological innovation ability. Based on the theory of Data Envelopment Analysis (DEA), the article introduces the input-oriented C²R model and C²GS² model to conduct a comprehensive evaluation of enterprise technological innovation capability, which enables companies to understand their own potential and shortages in the activities of technological innovation, sums up experience to fill gaps and improve enterprise competitiveness of core technology.

Keywords—Self-technological innovation capability; evaluation; index system; Data Envelopment Analysis (DEA)

I. INTRODUCTION

With the acceleration of world economic integration and the arrival of knowledge economy era, innovation has become the only way for the development of enterprises, but lacking of core technology and independent intellectual property restricts the efficiency of China's production and sustainable development, Chinese enterprises now must pay attention to their own technological innovation, developing the core technologies with independent intellectual property, so enterprise independent innovation capacity should correspond to enterprise competitiveness which under the conditions of a market economy. Scientific and reasonable evaluation of enterprise self-technological innovation capability is important for enterprise to choose their own models of technological innovation, to make technology innovation policy and improve their own level of technological innovation.

II. THE CONNOTATION OF SELF-TECHNOLOGICAL INNOVATION

A. The Connotation of Technological Innovation and Self-technological Innovation

With the continuous development of technological innovation and research, the concept of technological innovation has also expanded continuously. OECD defines the technological innovation as a significant technological change of new products and new skills, as well as product and skills. American Enterprise (P.F. Drucker) acclaims that the actions of technological innovation are giving resources to form a new capacity of creating wealth. The CPC Central Committee and State Council in “The Decision of Strengthening the Technological Innovation, Developing High-tech and Realizing the Industrialization” defines the technological innovation as the new knowledge and new technologies in the enterprise applications and using the new skills, new methods and management models to improve the quality of the products and produce new products, provide new services, occupying the market and achieve the market value.

Self-technological innovation is the advanced form of technological innovation with emphasis on the autonomous factors in the technical innovation process, therefore, the enterprise's real ability is becoming particularly important. This paper argues that self-technological innovation means that the enterprise uses its own research and development (also can make use of external force, but not solely rely on external forces) to break through the technical difficulties and complete some technological breakthroughs, besides, on this basis, to develop the products that own the independent intellectual property rights. The most prominent and important feature is to have the independent intellectual property rights.

B. Technological Innovation Capability and Self-technical Innovation Capability

The technological innovation capability of enterprises occupies an important position and also is the core of enterprise technological capability development. At present, the domestic and foreign scholars and research institutions have not yet reached the unity to the definition of "technological innovation capacity", because they don’t have the same angle in analyzing the problems and varies in decomposition of the elements of technical innovation. Representative points are: Bargelmm and MAMaidigu (1988) think that the enterprise technological innovation capacity is a series of comprehensive features which support the business strategy of technological innovation of enterprises. It includes the allocation of available resources and the understanding of the development of the industry, the understanding of technological development, structural and cultural conditions, strategic management capacity; DLBarton (1992) acclaims that the core of technological innovation capacity is the people with professional knowledge, technology systems, management capability and enterprise values; Xu Qingrui and Wei Jiang (1996) analyze from a technical process point of view that the structural elements of self-technological innovation capacity includes R&D capacity, production...
capacity, marketing capacity, organizational capacity; these five areas. The degree of enterprise technology innovation reflects the technological level of products, the degree which can meet the needs of the market, the capacity for innovative products into production and market-oriented capabilities; Fu Jiaji (1998) thinks that the technological innovation capacity is the core of enterprise development. From the fundamental nature of technological innovation, the basic processes of technological innovation, the inspiration of the successful technological innovation, as well as the survey results of the technological innovation and other aspects we can see that the enterprise technological innovation capacity should be broken into the ability of the investment of innovating resources, the ability of innovation management, the ability of innovation orientation, research and development capacity, manufacturing capacity and marketing capacity.

Comparing with the technological innovation, the self-technical innovation places much more emphasis on self-autonomy of technological innovation, that is, the autonomy of the enterprise in the process of innovation, as well as the speciality of the innovation products, therefore, the basis of self-technological innovation capacity is stronger than the technological innovation. The capacity of the enterprise self-technological innovation determines whether the enterprise could success in the technical innovation, and self-technological innovation is the metric ruler of enterprise's ability to perform the work. Clearly, self-technological innovation demands more than technological innovation in the ability of the enterprises.

The formation of self-technological innovation capacity should have the basic characteristics of the following aspects: first, the independent intellectual property rights, so as to enhance their ability to compete in the market; second is the emergence of new products which have the market value, that is an important performance of the formation of self-technological innovation capacity; third is to form a strong research and development system which use basic research as the support, applied research and the operation research of the integration of scientific application, which is the basis of creating and maintaining self-technological innovation capacity; fourth, as the formation of a self-technological innovation system which include a theoretical research and practice performance and companies characteristics in this industry to achieve a high-level enterprise self-technological innovation.

III. THE SELECTION OF ASSESSMENT METHOD AND THE ESTABLISHMENT OF INDEX SYSTEM

A. The selection of Evaluation Method

There are two issues to be addressed before the evaluation, the selection of evaluation methods and the establishment of index system. At present, domestic and foreign scholars evaluate the technological innovation capability of enterprises applied many methods, there are analytic hierarchy process(AHP), fuzzy comprehensive evaluation method, gray comprehensive evaluation method, principal component analysis, osculating value method and so on. Technological innovation as a system engineering which undergoing the research and development, achievement transformation, the scale of production and sales to gain market management, is one complex system with multiple inputs and multiple outputs. However, the methods above have not evaluated technological innovation capability of enterprises from the input-output point. Therefore, DEA is particularly suitable for analyzing multiple inputs and multiple outputs production systems. DEA can be used to optimize the performance measure of each decision making unit (DMU), and DEA doesn't need any priori information on the weights among input and output factors. These characteristics of DEA are suitable for the evolution of enterprises technological innovation capability. DEA is used to establish a best practice group among a set of companies and to identify the enterprises that are inefficient when compared with the best practice group. DEA also indicates the best way to improve innovation efficiency of inefficient enterprises, thereby improving their technological innovation capability. Therefore, this paper applies DEA approach to evaluate the enterprise independent technological innovation.

B. Construction of Evaluation Index System

1) Principles of the assessment index system

Corporate innovation activities are multi-level dynamic system which involves many factors, combining with characteristics of Chinese enterprises technological innovation, corporate self-evaluation index system of technological innovation should be designed as the following principles:

a) Scientific principle: Scientific is the basis to ensure the accuracy and reasonableness of evaluation results, which mostly depends on the rationality of index constitution, standards, procedures, etc. Therefore, the index system must be designed in a scientific way, the selection of indicators should focus on the nature of technological innovation and cover the most important factors of enterprise technological innovation capability. To objectively reflect the inherent laws of enterprise self-technological innovation, the indicators must based on the special investigations and researches, qualitative and quantitative combined, and strive to comprehensively and objectively describe the status of enterprise independent innovation capability.

b) Principle of comparability: A set of evaluation index system is a comprehensive assessment of many enterprises, the evaluation index system must be designed to take full account of the various statistical indicators of the differences among enterprises. When choosing specific indicators the system must be given a common meaning of indices, statistics caliber and range should be consistent as far as possible in order to ensure the comparability of indexes.

c) Independence principle: In order to ensure the independence and optimization of evaluation index, the

---

1 Charnes,A.,Cooper,W.W.,Golany,B.,Seiford,L.,Stutz,J.1985. Foundations of Data Envelopment Analysis for Pareto–Koopman efficient empirical production functions. Journal of Econometrics30,P16.
evaluation indices must have good coordination so as to reduce overlap in the conception and relevance in statistics, let alone serious recurrence relationship and inclusive relationship.

d) Operability principle: The indicators should be obtained or calculated from a variety of internal accounting data and statistical data. Therefore, based on the independent innovation capacity of enterprise, the index system should take into account reliability of the quantitative indicators and data.

2) Construction of evaluation system

According to the principles of evaluation index system of enterprise self-technological innovation capability and combining with the characteristics of DEA approach, this paper takes enterprise self-technological innovation process as the main line, on the basis of enterprise independent R&D abilities, self-transformation abilities, self-management abilities and independent marketing abilities, establishes an appropriate evaluation index system. Obviously, it will provide ideas and ways for enterprises to improve self-technological innovation capability. The evaluation index system is constructed as follows (Table 1):

   a) Independent R&D capabilities: The basic method of autonomous technological innovation is the enterprise itself to carry out a solid R&D, and the main purpose of R&D doesn’t help companies use technology imported from the outside, but to create new knowledge. Independent R&D capability is technical prerequisite and foundation of self-technological innovation capability. Inputs include the intensity of R&D investment, the intensity of R&D personnel quality-quantity, the input intensity of non-R&D, while the outputs include the number of patent, the proportion of independent innovation products, output ratio of independent products and the R&D success rate of independent product.

   b) Transformation capability of self-technological innovation: R&D activities and results such as new products, new equipment and new techniques just entering production activities, can launch on the market, resulting in economic and social benefits. Self-transformation ability of technological innovation can be said that the accumulation of independent innovation capacity, input indicators, including technical level of production equipment, composition of production personnel. The outputs are labor productivity and new product sales margins.

   c) Management capability of self-technological innovation: Of course, enterprise self-technological innovation can’t do without certain material conditions, but all of these conditions depend on human resources. Owning a good of organization and management system can make up defects that appeared in the process of enterprise self-technological innovation. What’s more, management capacity of enterprise technological innovation is not only confined to the enterprise's internal environment, but also reflected in the communication and collaboration with the external environment (such as government). So the author regards the government’s supports as input indicator of technological innovation, and the outputs are independent innovation strategy, innovation mechanism, frequency of innovation and power of information collection.

| Table 1: Evaluation Index System of Enterprise Self-Technological Innovation Capability |
|------------------------------------------|----------------------------------------------------------------------------------|
| Evaluation index system of enterprise self-technological innovation capability |                                      |
| Independent R&D capability               | Inputs: Intensity of R & D investment, Intensity of R&D personnel quality-quantity, Intensity of non-R & D inputs. |
|                                         | Outputs: Number of patent, The rate of independent innovation products, Output ratio of independent products, R&D success rate of independent product. |
| Transformation of self-technological innovation capability | Inputs: Technical level of production equipment, Composition of production personnel. |
|                                         | Outputs: Labor productivity, New product sales margins. |
| Management capability of self-technological innovation | Inputs: Government’s support. |
|                                         | Outputs: Independent innovation strategy, Innovation mechanism, Frequency of innovation, Information collection power. |
| Marketing capability of self-technological innovation | Inputs: Intensity of investment in marketing costs, The level of market research, The fitness of distribution network. |
|                                         | Outputs: Market share of new products, Returns of new products. |

d) Marketing capabilities of self-technological innovation: Self-marketing capabilities of technological innovation reflect the consumer’s preference to new products, and also embody the innovative products and market share. Input indicators include the intensity of investment in marketing expenses, market research level, the fitness of distribution network, the output indicators, are the market share of new products and return of new products.
IV. DEA MODEL

DEA was developed by Charnes A. and Cooper WW and provides a nonparametric methodology for evaluating the efficiency of every set of comparable DMUs, which relative to one another. In other words, the focus of DEA is on the individual observations as represented by optimizations, in contrast to the focus on the averages and estimation of parameters that are associated with a single-optimization statistical parametric approach. The major advantage of the DEA method is that DEA doesn’t require any assumptions about the function form. The performance measure of multiple inputs and multiple outputs production system can hardly be described by a concrete function form.

According to the DEA theory, this paper combined two-stage method with DEA models to evaluate the enterprise self-technological innovation capability. In the first stage, using C2R and C2GS2 model, respectively, this paper evaluates enterprise self-technological innovation capability from the points of independent R&D capabilities, self-transformation abilities, self-management abilities and independent marketing abilities; in the second stage, regards the technical efficiency results from the four dimensions of the first stage as dependent variables, and then analyzes the main factors effect on the results from the four dimensions of the first stage as dependent variables.

It provides a scientific basis for enterprises to improve self-technological innovation ability.

A. The first Stage Model

In order to overcome one-sidedness of the evaluation, this paper, based on the input-oriented C2R model and C2GS2 model, evaluates technical efficiency by C2R model which assumes the returns to scale is constant, and evaluates pure technical efficiency of C2GS2 model which allows the returns to scale is variable. Then the returns to scale can be defined by the ratio of technological efficiency of C2R model to pure technological efficiency of C2GS2 model.

The input-oriented C2R model was used to determine the best-practice frontier, and all DMUs are operating at constant-inputs-to-scale. The technical efficiency problem can be expressed by the following model.

\[
\begin{align*}
\Delta^*_{C^2GS^2} & = \inf \left\{ \sum_{j=1}^{n} X_j \lambda_j - S^+ = Y_0 \right\} \\
\theta & \geq 0, j = 1, \ldots, n \\
\hat{e} & = (1,1,\ldots,1)^T \in E^m, e = (1,1,\ldots,1)^T \in E^s \\
S^+ & \geq 0, S^- \geq 0
\end{align*}
\]

Where \( \theta \) is the technical efficiency; \( X_j \) is the input for firm \( j \) and \( Y_j \) is the output for firm \( j \); \( X_0 \) and \( Y_0 \) are the input and output of the DMU evaluated; \( m \) and \( s \) are, respectively, the number of inputs and outputs; \( \epsilon (\epsilon>0) \) is a non-Archimedean infinitesimal; \( n \) is the number of enterprise; \( S^+ \) and \( S^- \) are input and output slack variables respectively.

Suppose optimal solutions of model(1) are \( \lambda^0 \), \( S^{-0} \), \( S^{+0} \), \( \theta^0 \) if \( \theta^0=1 \) and both \( S^{-0} \) and \( S^{+0} \) are more than zero, then enterprise \( j_0 \) is DEA weak-efficient, that is for \( j_0 \)th DMU, the input \( X_j \) can be reduced \( S^{-0} \) while maintaining the original output \( Y_j \) unchanged, or increasing output but input keeps invariant; while \( \theta^0=1 \) and both \( S^{-0} \) and \( S^{+0} \) are equal to zero, the enterprise \( j_0 \) is DEA efficient, that is, the output \( Y \) has reached the optimal on the basis of original input \( X \); if \( \theta^0 \) is less than one, then the \( j_0 \)th DMU is DEA inefficient.

In order to divide technical efficiency into two parts, \( C^2GS^2 \) model relax the constraints on returns to scale, assuming that returns to scale exist, its production possibility set is a polyhedral convex set, which was determined by the assumption of convexity, ineffectiveness and minimum. \( C^2GS^2 \) model only used to evaluate the decision-making unit of pure technical efficiency, that is, model (2).

\[
\Delta^*_{C^2GS^2} = \left[ \min \left\{ \sum_{j=1}^{n} X_j \lambda_j - S^+ = \theta Y_0 \right\} \right]
\]

Then DMU \( j_0 \) is termed efficient if and only if the optimal value \( \theta^0 \) is equal to 1 and all the slack variables are zero. This model allows variable-inputs-to-scale.

B. The second Stage Model

Applying the DEA method from four different aspects to evaluate can provide an effective method to improve, however, it does not able to explain the overall efficiency of technological innovation. Enterprises focus on improving one aspect is at the price of reducing the other efficiencies. As for this, during the second stage, the dummy variable \( 1 \) will be used as the sole input for the DEA model.

---

\[\text{Charnes, A.}, \text{Cooper, W.W.}, \text{Golany, B.}, \text{Seiford, L.}, \text{Stutz, J.} 1985. \text{Foundations of Data Envelopment Analysis for Pareto–Koopman efficient empirical production functions. Journal of Econometrics}30,16–29.\]

---

\[\text{Rouatt, Stephen James, Two stage evaluation of bank branch efficiency using data envelopment analysis}\text{[1]. Masters Abstracts International,}\]
The outputs will be the value of technical efficiency that results from the first stage, just as figure 1. Thus, four aspects of enterprise self-technological innovation capability will be integrated.

![Table and Diagram](image)

In the second stage, considering inputs and outputs, this paper establishes a new objective function based on slack-based variable model (SBM), such as model (3).

\[
\begin{align*}
\min \rho &= \left( \frac{1}{m} \sum_{i=1}^{m} X_{i0} - S_i^- \right) \left( \frac{1}{s} \sum_{r=1}^{s} Y_{r0} + S_r^+ \right)^{-1} \\
\sum_{j=1}^{n} X_j \lambda_j + S^- &= \theta X_0 \\
\sum_{j=1}^{n} Y_j \lambda_j - S^+ &= Y_0 \\
\lambda_j &\geq 0, j = 1, \ldots, n \\
\hat{e} = (1,1,\ldots,1)^T &\in E^m, e = (1,1,\ldots,1)^T &\in E^s \\
S^- &\geq 0, S^+ &\geq 0
\end{align*}
\]

Where m and s, respectively, are the number of inputs and outputs, the meaning of the other indicators is the same as model (1). If \( \rho \) is equal to one, then \( j_0 \)th DMU is DEA efficient; otherwise, \( j_0 \)th DMU is DEA inefficient. Because the input is a dummy variable 1 (that is \( X_{i0} \) is equal to one) and \( S_i^- \) is zero, then model (3) can be simplified as model (4).

\[
\min \rho = \left( \frac{1}{s} \sum_{r=1}^{s} Y_{r0} + S_r^+ \right)^{-1} \quad (4)
\]

Cooper did not give weights of slack variable in the formula above, that is, the contribution of different dimensions is the same to overall efficiency. According to the preferences of decision makers, they can give different weights to four dimensions, such as the majority of enterprises underline independent R&D capability in the process of self-technological innovation. According to SBM model, it demands to make indexes being dimensionless, due to the results of the first stage are already dimensionless value, the slack variable can be directly conferred on weights in the objective function. Introducing new constraint vector of weights, the objective function (4) can be transformed as follows:

\[
\min \rho = \left( \frac{1}{s} \sum_{r=1}^{s} Y_{r0} + V_r + S_r^+ \right)^{-1} \quad (5)
\]

V. CONCLUSIONS

On the basis of the connotation of the self-technological innovation and DEA model, this paper establishes evaluation index system of enterprise self-technological innovation capability, and then develops a two-stage DEA model to measure the overall efficiency for the enterprise independent technological innovation capability. Throughout the study, special emphasis was placed on how to present the DEA results to management so as to provide more guidance to enterprises on what to improve and how to accomplish the changes. In addition, it will help companies enhance their core competitiveness.

REFERENCES

[1] Sun Ximing. Study on the Evaluation of Enterprise Technical Innovation Capability. Doctor Degree Dissertation of Huazhong University of Science and Technology, 2003, pp.4-5.

[2] Wei Jiang, Xu Qingrui. Study on Coordination of Technological Capability and Technological Innovation Capability. Management Research, 2006.No12.

[3] Sun Ximing. Study on the Evaluation of Enterprise Technical Innovation Capability. Doctor Degree Dissertation of Huazhong University of Science and Technology, 2003, pp.4-5.

[4] Charnes, A., Cooper, W.W., Golany, B., Seiford, L., Stutz, J. 1985. Foundations of Data Envelopment Analysis for Pareto–Koopman efficient empirical production functions. Journal of Econometrics 30, 16–29.

[5] Song Xiaohong. Comprehensive Evaluation on the Independent Innovation Ability of Manufacturing Enterprises with DEA Method. Commercial Research, June 2008.

[6] Rouatt, Stephen James. Two stage evaluation of bank branch efficiency using data envelopment analysis[J]. Masters Abstracts International, Volume:41-06, page:1810,2003.

[7] Charnes, A., Cooper, W.W., Seiford, LM and Tone, K. (eds.), Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References, and DEA-Solver Software [M]. Kluwer Academic Publishers, Boston, 2000