Measurement Research on Influential Effect of Standardization on Technological Innovation

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Abstract. There is a close relationship between standardization and technological innovation. Based on the analysis of the function mechanism of standardization on technological innovation, this paper has established measurement indexes of the influential effect of standardization on technological innovation. As structural equation modeling (SEM) has its own advantages over statistical methods such as correlation analysis, regression analysis and path analysis, this study attempts to measure the influence degree of standardization on technological innovation by adopting SEM method, and has established a measurement model and a structural equation model for the standardized technological innovation effect. In addition, the study has discussed the fuzzy DEA method to analyze the standardized technological innovation effect of DMUs, established the fuzzy DEA-based index system for evaluating standardized technological innovation effect, constructed the fuzzy DEA model for evaluating standardized technological innovation effect, and provided the solution process of the model.

1. Introduction
Standardization is an activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimum degree of order in a given context. In particular, the activity consists of the processes of formulating, issuing and implementing standards. Important benefits of standardization are improvement of the suitability of products, processes and services for their intended purposes, prevention of barriers to trade and facilitation of technological cooperation [1]. Standardization and technological innovation have become more and more inseparable. As technological innovation provides the knowledge base for standardization, standardization also affects technological innovation through different ways. Relevant theories and researches on technological innovation have been relatively mature, but there are few theoretical and empirical researches on the measurement of the impact of standardization on technological innovation, hence the explanatory power is limited. More researches focus on measuring economic benefits of standardization. In 1999, German scholars such as Knut Blind used the Cobb-Douglas production function for the first time to analyze Germany’s economic development from 1960 to 1996. According to the research, standardization contributed about 0.9 percentage points to the annual economic growth rate of 3.3% [2]. In 2002, after adjusting the German econometric model, the UK came to the following conclusion: from 1948 to 2002, about 13% of the economic growth was related to standards [3]. In 2005, the UK Department of Trade and Industry (DTI) released a research report on the impact of standards on macro-economy. The report used data from 1948 to 2002 to analyze the long-term relationship between changes in the net stock of standards and productivity growth, and argued that there was a positive and significant relationship between standards and UK productivity [4]. In 2015, the British Economic and Business Research Center (CEBR) published a research report entitled "The Economic Contribution of Standards to the UK Economy". The report, using a research method similar...
to that of 2005, re-estimated the impact of standards on the UK productivity from 1921 to 2015. It was calculated that standards promoted the annual productivity growth by 37.4% [5]. In 2009, France carried out a research project on the economic benefits of standardization, which analyzed the macro-economy from 1950 to 2007 and studied the relationship between standards and economic growth. The conclusion of the study was that standardization contributed 0.81% to France's annual economic growth rate. In 2010, International Organization for Standardization (ISO), with the support of Roland Berger, developed a methodology to evaluate and quantify economic benefits of standards. Based on value chain analysis, the methodology is for use by ISO member countries in designing and carrying out such kind of research [6]. Zhang Changyuan (2018) used the functional coefficient method to evaluate the benefits of enterprise technology standardization on the basis of a given index system [7]. Ruan Jinyuan et al. (2019) established an evaluation system framework for the economic benefits of enterprise technology standardization from the perspective of various cost savings after technology standardization [8]. Song Min et al. (2018) applied the data envelopment analysis (DEA) to the evaluation of economic benefits of enterprise standardization for the first time, and provided an evaluation research model of a virtual enterprise in terms of input and output of technical standards, which has certain theoretical development significance [9].

2. Function mechanism of standardization on technological innovation

2.1. Standards indicate the direction for technological innovation

As for the general direction specified by the technological paradigm, technological innovation will develop along the technological track. Technological innovators will succeed relatively easily if they carry out innovation activities along this track, while innovators outside the track will be separated from mainstream technologies and difficult to be recognized by the market [10]. In the evolution process of technology track, standardization gradually selects diversified technologies, converges on diversity, and finally restricts diversified technologies into unified technologies. The results directly guide the process of technological innovation, prevent technological innovation and its key elements from getting out of control and deviating, and enable them to be brought to an efficient development track. At the beginning, standards make basic restrictions on the direction of technological innovation and define a clear-cut category. Then, in this specific category, one or more standards are determined. The standards guide the investment direction of enterprise R&D through detailed regulations on the attributes of new products or new services, thus achieving the goal of restricting the direction of technological innovation. By this way, new technologies and services quickly realize economies of scale, and the improvement time of new technologies and services are reduced. After standardization converges on diversity, it draws a common starting line for all technological innovations, and the converged standard will become a new starting point for technological innovation. With the development of time, technological innovators will introduce a variety of new technologies and services and put them into the market to join the competition. At this point, it comes to the stage of standards’ restriction on diversified technologies again, and the cycle continues. Technological innovation advances and develops under the continuous constraints of standards.

2.2. Standards provide the platform for technological innovation

Standards accumulate knowledge for technological innovation and improve the starting point of technological innovation. Technological innovation is further developed based on the experience and technology summarized by predecessors. Without accumulation, there would be no technological innovation. Research and development personnel, construction engineers and marketing experts use standard documents as important information resources about the technical status. Current advanced management methods, technologies and working experience are accumulated by standards, and then promoted and popularized during the implementation of such standards. At the same time, more advanced management methods, technologies and experience will be innovated, which will be accumulated again by revising or re-formulating standards. The disclosure of information and knowledge in the standards enables the whole process of technological innovation to obtain such information and knowledge, and serves as a better platform for researchers to accumulate technological
innovation. In the process of implementing the standards, there will be new experience and technological re-innovations, which will revise the original standards to form new standards, that is, the re-accumulation of information and knowledge. The process of formulation - implementation - revision of standards is the process of innovation - popularization - re-innovation of technology and experience. Standards provide a foundation and platform for the further development of technological innovation, strengthen the motivation of technological innovation, and improve the efficiency and starting point of technological innovation.

2.3. Standards can help reduce information asymmetry in the consumer market

The information provided by the standard on innovative products and services is credible and it clearly stipulates the quality and function of products. The formulation and implementation of standards, namely, the process of standardization, can greatly reduce the information search cost of consumers, reduce the information asymmetry in the market, make consumption decisions that a rational-economic man should make, and promote transactions. This can eradicate the "lemon market" phenomenon to some extent, help restore the market function and overcome the "adverse selection" of inferior products driving out quality ones. This is conducive to consumers to fully understand the specific information of innovative products and services, and make clear comparisons, so that the consumers can have a correct knowledge of the products they have purchased and the information of technological innovation achievements can be widely disseminated, thus promoting technological innovation.

Where there are three addresses, you should insert numbered superscripts 1, 2 and 3 to link surnames to addresses and then insert footnotes 4 and 5. Note that the first footnote in the main text will now be number 6.

3. Establishment of the measurement indexes of standardized technological innovation effect

3.1. Purposes and principles of index selection

3.1.1 Purpose of index selection

In the process of systematic evaluation, the following two purpose need to be achieved first to set up corresponding index: First, a scientific, reasonable and operable evaluation system can be formed to clarify the future evaluation work. Second, the indexes can clearly reflect the main process of technology standardization of enterprises, so as to understand and evaluate the innovation effect of standardized technology while providing more reference bases for subsequent research and guidance.

3.1.2 Principles of index selection

- The evaluation indexes can highlight the impact of standardization. The design of the indexes should strive to comprehensively, objectively and accurately describe the impact of standardization on technological innovation.
- Use of quantitative indexes. The evaluation of the innovation effect of standardized technology requires quantitative methods to measure the effect of standardization. Therefore, quantitative indexes that can be expressed by specific numerical values must be selected.
- The principle of incompatibility. Crossed and repeated indexes should be avoided as much as possible so as to ensure the independence of indexes.
- The principle of scientificity. The basic concepts and logical structure of the index system should be rigorous and reasonable, and conform to the reality of standardization work. The indexes in the evaluation system should have clear connotation and scientific explanation.
- The principle of system optimization. In the selection of the number of indexes, try to reflect the content of the evaluation object more comprehensively and systematically with fewer indexes to avoid a numerous and jumbled the index system. Through the organic connection of indexes, make each element and the structure of the system meet the requirements of system optimization.
- The principle of operability. The design of indexes should be convenient for data collection. When designing the index system, the concept should be clear and can be verified repeatedly.
Goal-oriented principle. The design of index system should be able to objectively reflect the current situation and existing problems in the standardization process.

3.2. Construction of index system

The input factors of technological innovation mainly include technology, information, equipment, capital and personnel, etc. Standardization will have an impact on these factors. The knowledge stock provided by technical standards can guide enterprises to choose technologies suitable for their own conditions for research and development, and introduce corresponding patents and copyrights, etc., so as to promote new technologies to continuously replace old technologies and provide a higher technology platform for industrial technological innovation. Technical standards cover a large amount of information related to product specifications, process flow, inspection, weighing and measurement, providing necessary technical information for product innovation and process innovation and reducing the uncertainty of technological innovation. Technical standards directly affect the performance and specifications of production equipment and inspection equipment, accelerate the standardization of production equipment and inspection equipment, and reduce the rate of unqualified products in the production and sales stages. The technical standards define the functional demand target of capital investment in the market for technological innovation, enables capital investment to take effect in a short period of time, forms a preemptive advantage, and avoids the risk of capital investment to a certain extent. Technical standards provide technicians with reserves of technical knowledge and evaluation indexes of technical level. By interpreting technical standard documents, technicians can more clearly understand the functional requirements of consumers for products so as to fully meet the functional requirements of the market. During product development, all kinds of advanced standardized technology and methods and management experience are actively promoted, which can change the standardization of the research and development process from the original isolated business work of specialized departments to a system engineering that takes into account the whole process of technology and management, including product research and development, use, maintenance, repair and scrapping, and even the improvement of the next generation. The direct effect of strengthening the promotion of advanced standardization technology and standardization management methods is to improve the standardization level of products, make them form standardization, serialization and combination, improve their versatility, interchangeability and maintainability, enhance their testability, etc., and further improve the market competitiveness of products.

Based on the above analysis, the design of the evaluation index system of standardization technology innovation effect is shown in Table 1:

| Target Layer | Level 1 Index | Level 2 Index |
|--------------|---------------|---------------|
| The influence effect of standardization on technological innovation | Degree of standardization | Degree of design standardization |
| | | Degree of cost standardization |
| | | Degree of component standardization |
| | | Degree of quality standardization |
| | | Degree of standardization in development and implementation |
| Technological innovation | Innovation level | |
| | Innovation efficiency | |
| | Patents | |
| | Output of new products | |
| | Enterprise value | |
| | Financial performance | |
4. Measurement of influential effect of standardization on technological innovation based on SEM

Compared with other methods, Structural Equation Modeling (SEM) has the following advantages: it allows the existence of measurement errors or residuals between external dependent variables and internal dependent variables; it can simultaneously deal with measurement relations and structural relations between variables in one model. Therefore, we try to select SEM as the research method to evaluate the technological innovation effect of DMU standardization.

4.1. Characteristics of SEM

Compared with statistical methods such as correlation and regression analysis and path analysis that study the relationship between variables, SEM has the following characteristics: (1) Multiple dependent variables can be considered and processed at the same time; (2) Allow independent variable items and dependent variable items to contain measurement errors; (3) Allow latent variables to be composed of multiple explicit index variables, and estimate the reliability and validity of index variables at the same time; (4) A more flexible measurement mode than the traditional method can be adopted. In the traditional method, items are more attached to a single factor, while in SEM, an index variable can be subordinate to two latent factors; and (5) The relationship between latent variables can be constructed and the coincidence degree between the model and the data can be estimated.

4.2. Numbering establishment of measurement model and SEM of standardized technological innovation effect

According to the analysis of the concepts of standardization and technological innovation, a measurement model is established, as shown in Table 2.

Table 2. Measurement models of standardization and technological innovation

| Exogenous potential variable | Measured variable                                      | Error |
|------------------------------|--------------------------------------------------------|-------|
| Degree of standardization    | Degree of design standardization                        | e₁    |
|                              | Degree of cost standardization                          | e₂    |
|                              | Degree of component standardization                     | e₃    |
|                              | Degree of quality standardization                       | e₄    |
|                              | Degree of standardization in development and implementation | e₅    |
| Technological innovation     | Innovation level                                       | e₆    |
|                              | Innovation efficiency                                  | e₇    |
|                              | Patents                                                | e₈    |
|                              | Output of new products                                 | e₉    |
|                              | Enterprise value                                       | e₁₀   |
|                              | Financial performance                                  | e₁₁   |

With the established measurement model, the corresponding SEM can be established, as shown in the figure 1.

With appropriately selected sample data and SEM analysis software such as LISREL, AMOS, etc., the corresponding calculation results of the influence of standardization on technological innovation effect can be obtained.
Figure 1. SEM for measuring standardized technological innovation effect

5. Measurement of influential effect of standardization on technological innovation based on fuzzy DEA

Data Envelopment Analysis (DEA) is suitable for performance evaluation of multiple decision making units (DMUs) with multiple types of inputs and outputs. If the DMUs have identical targets and tasks, external environments, input and output indexes, the relative efficiency of them can be measured by DEA. The evaluation of standardized technological innovation effect is sometimes difficult to be explained by specific quantitative indicators, but the role of standardization can be "felt". This attribute characteristic leads to a large number of fuzzy factors in the evaluation of standardized technological innovation effect. Fuzzy DEA can be used to compare the relative situations of the standardized technological innovation effect of DMUs, so it can better reflect the real situation.

5.1. Fuzzy DEA model for evaluation of standardized technological innovation effect

Fuzzy DEA model is based on deterministic DEA model. Assume that there are n objects to be evaluated (also called n DMUs), each DMU has m types of inputs and s types of outputs, and their corresponding weight vectors are respectively written as: \( V = (v_1, v_2, \cdots v_m)^T \), \( U = (u_1, u_2, \cdots u_s)^T \). The j-th input and output of the n DUMs are respectively written with vectors as follows:

\[
\hat{X}_j = (\hat{x}_{1j}, \hat{x}_{2j}, \cdots \hat{x}_{mj})^T, j = 1, 2, \cdots n
\]

\[
\hat{Y}_j = (\hat{y}_{1j}, \hat{y}_{2j}, \cdots \hat{y}_{sj})^T, j = 1, 2, \cdots n
\]
Compared with deterministic DEA, the input and output indexes are fuzzy numbers. Therefore, the corresponding evaluation model becomes:

\[
\begin{align*}
\min_{\theta} & \quad \sum_{j=1}^{n} \bar{x}_j \lambda_j + S^- = \theta \bar{x}_0 \\
\text{s.t.} & \quad \sum_{j=1}^{n} \bar{y}_j \lambda_j - S^+ = \bar{y}_0 \\
& \quad \lambda_j \geq 0, j = 1, 2, \ldots, n \\
& \quad S^+ = (s_1^+, s_2^+, \ldots, s_n^+) \geq 0 \\
& \quad S^- = (s_1^-, s_2^-, \ldots, s_n^-) \geq 0 
\end{align*}
\]

If the fuzzy DEA model and the corresponding deterministic DEA model have the same economic significance, its corresponding fuzzy production possibility set is:

\[
\bar{T}_{C^{2-R}} = \{(\bar{x}, \bar{y}) | \sum_{j=1}^{n} \lambda_j \bar{x}_j \leq \bar{x}, \sum_{j=1}^{n} \lambda_j \bar{y}_j \leq \bar{y}, \lambda_j \geq 0, j = 1, 2, \ldots, n \}
\]

Similarly, other similar fuzzy DEA models can be established.

As for the relative effectiveness of fuzzy DEA model, the theoretical research results have also shown that when there are fuzzy numbers in the input and output indexes of the DMUs, it's not appropriate to simply take a certain definite value and use the deterministic DEA model to evaluate the relative effectiveness of the DMUs. This approach may result in a situation where "valid units are rated as invalid and invalid units are rated as valid". Therefore, the evaluation method of DMU relative effectiveness used under fuzzy conditions will be different from that used under deterministic conditions. All possible values of input and output indexes of all fuzzy DMUs should be comprehensively considered.

5.2. Evaluation index system of standardized technological innovation effect based on fuzzy DEA

Similar to DEA evaluation model used under deterministic conditions, DEA evaluation model used under fuzzy conditions needs an appropriate index system. According to the existing experience and the results of relevant research, the index system is set as shown in Table 3. (due to the use of fuzzy DEA for evaluation, the index system covers a wider range and allows some qualitative fuzzy indexes):

| Table 3. Evaluation index system of standardized technological innovation effect based on fuzzy DEA |
|----------------------------------|
| **Input index**                  |
| Research and development funds   |
| Number of R&D personnel          |
| Instrument and equipment costs   |
| Number of new product development projects |
| **Output index**                 |
| Revenue from sales of new products |
| Number of Invention patents owned |
| Number of patent applications    |

5.3. Model solving

Fuzzy DEA model is a linear programming model with fuzzy coefficients, also known as possibility linear programming model. Generally ranking criterion based on fuzzy numbers or the solution method based on cut sets are used for solution of fuzzy programming of this type. The basic idea is to transform fuzzy DEA into deterministic linear programming. We give the result without proof:

Based on the ranking criterion of L-R fuzzy numbers, the fuzzy DEA model can be transformed into the following deterministic linear programming model:
These two deterministic linear programming are the target values of the original fuzzy DEA model and provide \([\theta^*_0, (\theta^*)^*_0]\), a closed interval with \(\alpha\) as the cut set. From this closed interval, the decision
maker can get to know the change range of the relative effectiveness of the evaluated units under a certain confidence level.

6. Summary

Based on the mechanism of the effect of standardization on technological innovation, combined with the commonly used measurement methods, this paper selectively gives the structural equation model (SEM) and fuzzy DEA to measure the influential effect of standardization on technological innovation. SEM is rarely used to measure the influential effect of standardization on technological innovation. By establishing the measurement model and SEM with the exogenous latent variables "standardization degree" and "technological innovation", the influence of standardization on technological innovation can be determined. Compared with deterministic DEA, fuzzy DEA can better judge the correlation that includes qualitative indexes. For this reason, fuzzy DEA can be used to compare the relative situations of the standardized technological innovation effect of DMUs to better reflect the real situation. However, this paper only gives the analysis method and corresponding indexes, and analyzes the feasibility of the method, but provides no example with specific data. We will have further study in this aspect in the future.

7. References

[1] ISO/IEC 2004. ISO/IEC GIDUE 2 Standardization and related activities— General vocabulary. ISO Technical Paper.
[2] Knut Blind 1999. The Economics of Standards: Theory, Evidence, Policy. Glos: Edward Elgar Publishing Ltd.
[3] Shanghai Institute of Standardization 2007. Evaluation of Standardization Benefits and Cases. China Standard Publishing House.
[4] TEMPLE P, WITT R, SPENCER C 2005. Standards and long-run growth in the UK. DTI Economics paper, vol. 12, pp 39-60
[5] Cebr 2015. The Economic Contribution of Standards to the UK-Economy, Technical report.
[6] Roland Berger Stategy Consultants 2010. Economic Benefits of Standards: Implementation Guide, Technical report, ISO.
[7] Zhang Changyuan 2018. Application of Functional Coefficient Method in Economic Benefit Evaluation of Standardization, Metallurgical Standardization and Quality, vol 9, pp 27-29.
[8] Ruan Jinyuan, Wang Xinian, Ruan Jun 2019. Analysis and Research on Economic Benefits of Standardization, Standardization Report, vol 2 (4) pp 23-27.
[9] Song Min, Yu Xinli, Lu Lili 2018. DEA-based Benefit Evaluation of Enterprise Standardization, China Standardization, vol 10, pp 56-59.
[10] Giovanni Dosi, Christopher Freema, Richard Nelson, Gerald Silverberg, Luc Soete 1992. Technical Change and Economic Theory. Economic Science Press, pp 12

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