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An Empirical Study on Servitization Improve Manufacturing Enterprises' Innovation Capability

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The paper built a comprehensive evaluation model with improved Grey Correlation-fuzzy, and made an empirical research on the innovation capability of manufacturing enterprises in China. Evaluation results show that enterprises which have taken servitization strategy get higher index value than the enterprises have not, wherever in the enterprise innovation opportunity recognition capability, innovation process execution capability, innovation results evaluation capability, and innovation comprehensive capability.

1. Introduction

There are many factors which influence the innovation activities of enterprises, especially in the current trend of manufacturing servitization. In the case of innovation is increasingly becoming a system behaviour that involved multiple subjects and combined with each other in a variety of elements, requiring companies to have a more comprehensive and diversified innovation capability.
(Li et al., 2015) had researched 52 manufacturing companies and found that most of the companies' innovation efficiency is low because of their low scale efficiency. (Han and Wang, 2015) revealed that there are some internal driving factors like collaborative innovation willingness, as well as some external driving factors, such as the market competition pressure. (Joseph, 1982) believed innovation is the concept of a combined ability; it is a combination of technological innovation, system innovation capability and other factors together. (George, 2004) believed that product innovation is the result of joint action by three factors: technology, product and market space organization and management. (Yang, 2001; Liu, 2000) have done pioneering research of product innovation and found that product innovation is a comprehensive ability that the enterprise in order to occupy the market and gain inner profit. (Sun et al., 2010) selected 16 indicators from technology inputs and outputs, and put forward countermeasures on how to improve the technological innovation capability of enterprises.

2. Methodology

2.1 The selection of evaluation index

From the perspective of innovation process, the paper argues that innovation capability should include three sub abilities, innovation opportunity recognition capability, innovation process execution capability, and innovation result evaluation capability. The innovation opportunity recognition capability refers to the ability of enterprises to find, identify and capture/seize the innovation opportunities in changeable market environment. The innovation process execution capability stands for the ability of enterprises transforms innovative ideas into products or services, evading risk and creating profit for the enterprise. The innovation result evaluation capability means the ability that enterprises make a scientific evaluation and examination for innovation, and can reflect the innovation value accurately. The above three dimensions can be from the perspective of innovation process, reflecting innovation capabilities of manufacturing enterprises more comprehensively and give more consideration to the important role of customer as well as other members of the network in collaboration under the background of manufacturing servitization.
On the basis of literature study (Zheng and He, 2000; Liu 2007), the paper combined with the theorization, the comprehensiveness, the independence, the representative, etc. of constructing index system, based on the

trend of manufacturing servitization, determining the relevant secondary indexes respectively. As shown in Figure 1.

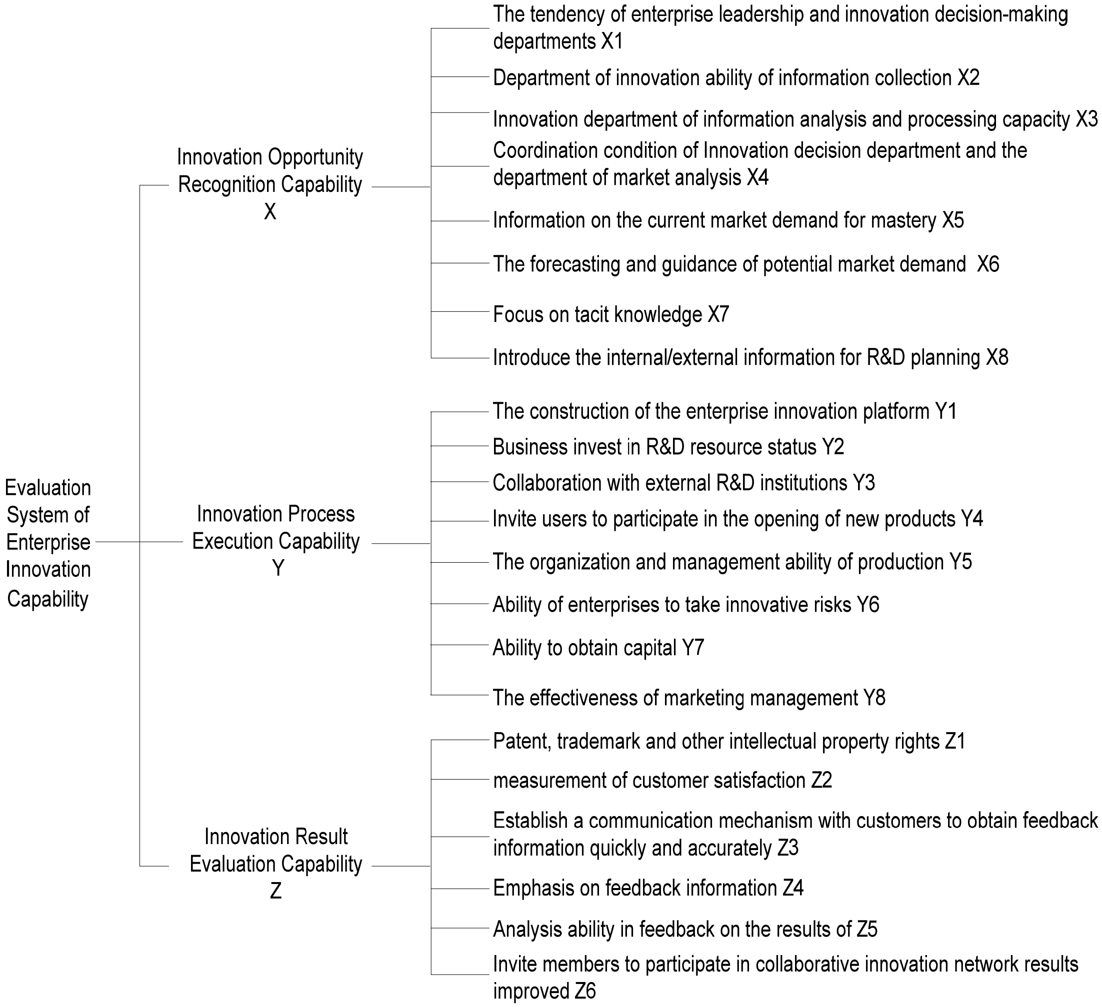

Figure 1: Evaluation system of enterprise innovation capability

2.2 Grey Correlation Degree analysis method to determine index weight

Using of the improved Grey Correlation Degree analysis method to operate and compute, is able to determine the overall impact on the index system of each subsystem of any indicators for the rest indicators, and thus determine the index weight. General steps are as follows:

For n companies to be evaluated $P^{(1)}$, $P^{(2)}$, …$P^{(n)}$,x_1,x_2,…, x_m are evaluating indicators, $P_{xi}^{(j)}$ stands the value of indicator x_i of company $P^{(j)}$ were evaluated on a fixed point.

Step 1: Do dimensionless processing for sequence of indicators – object

Usually, we need to do the dimensionless processing for sequence $x_1^{(p)}$, $x_2^{(p)}$,…, $x_m^{(p)}$. By using standardized dimensionless processing, change the data from $x_1^{(p)}$, $x_2^{(p)}$,…, $x_m^{(p)}$ into $\phi_1^{(x)}$, $\phi_2^{(x)}$,…, $\phi_m^{(x)}$.

Step 2: Calculate the square correlation degree

We choose each sequence from $\phi_1^{(x)}$, $\phi_2^{(x)}$,…, $\phi_m^{(x)}$. respectively as the mother sequence, and correspondingly the left sequence as a subsequence, then we got (m-1)×(m-1) amount of correlations and generated an m-order Correlation Matrix $\Psi_m^{(x)}$.

As a sequence cannot be calculated with itself, so the elements on the diagonal in this Correlation Matrix are empty, this has shown as follows:

$$\Psi_m^{(X)} = \begin{bmatrix} - & \xi_{12}^{(X)} & \cdots & \xi_{1m}^{(X)} \\ \xi_{21}^{(X)} & - & \cdots & \xi_{2m}^{(X)} \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{m1}^{(X)} & \xi_{m2}^{(X)} & \cdots & - \end{bmatrix} \tag{1}$$

The $\xi_{ij}^{(x)}$ denotes the degree of association between subsequence $x_j^{(p)}$ and the mother sequence $x_j^{(p)}$ which represents influence degree that X_i index reacted to index X_j,
Where, j=1, 2, …, n, i≠j,
Step Three: Determine $\triangle_i^{(x)}$ and then get its weights $a_i^{(x)}$
Determine the $\triangle_i^{(x)}$, which is evaluated as follows:

$$\Delta_i^{(X)} = \sum_{j=1, j\neq i}^{m} \xi_{ij}^{(X)} \tag{2}$$

, Where i=1, 2, …, m,

The $\triangle_i^{(x)}$ represents an overall influence which X_i carries to other indices, and also stands for the degree of importance in the whole index system.
Normalize for $a_i^{(x)}$, which is evaluated as follows:

$$a_i^{(X)} = \frac{\Delta_i^{(X)}}{\sum_{j=1}^{m} \Delta_j^{(X)}} \tag{3}$$

, where i=1, 2, …, n and $a_i^{(x)}$ is the weight of index X_i,

Meanwhile we got weight vector $A_m^{(x)}=(a_1^{(x)}, a_2^{(x)},\dots, a_m^{(x)})$ of index X_1, …, X_m.
Similarly, we got weight vectors of secondary indicators and first class indicators respectively, which are shown as follows:

$$A_X = \left(a_1^{(X)}, a_2^{(X)}, \cdots, a_8^{(X)}\right) \qquad A_Y = \left(a_1^{(Y)}, a_2^{(Y)}, \cdots, a_8^{(Y)}\right)$$

$$A_Z = \left(a_1^{(Z)}, a_2^{(Z)}, \cdots, a_6^{(Z)}\right) \qquad A = \left(a_1, a_2, a_3\right)$$

2.3 Calculation of Fuzzy Evaluation Matrix

We set $P_x^{(j)}=(P_{x1}^{(j)}, P_{x2}^{(j)},\dots, P_{xm}^{(j)})$ as an Object - Index Sequence that comes from company's (named $P^{(j)}$) statistics about X_1, X_2, …, X_m, Where i=1, 2, …, m, j=1, 2, …, n.

At the same time, we got $P_x^{(1)}, P_x^{(2)},\dots, P_x^{(n)}$ respectively.
It was assumed an optimal sequence $P_x^*=(P_1^*, P_2^*,\dots, P_m^*)$, which is operated as follows:

$$P_i^* = \max_{j=1,2,\cdots,n} \left\{P_{x_i}^{(j)}\right\} \tag{4}$$

, if index i takes the maximum value;

$$P_i^* = \min_{j=1,2,\cdots,n} \left\{P_{x_i}^{(j)}\right\} \tag{5}$$

, if index i takes the minimum value,

Where i=1, 2, …, m;

If the individual components of the resulting sequence ($P_x^*, P_x^{(1)}, P_x^{(2)},\dots, P_x^{(n)}$) have a different dimension, the correlation coefficient cannot be calculated, and then they need to be dimensionless, as $P_x^*, P_x^{(1)}, P_x^{(2)},\dots, P_x^{(n)}$ is the Object - Index Sequence, we usually choose dimensionless method of range dealing. After that we symbolize it as $C_x^*, C_x^{(1)}, C_x^{(2)},\dots, C_x^{(n)}$.
Now we set C_x^* as mother sequence, $C_x^{(1)}, C_x^{(2)},\dots, C_x^{(n)}$ as subsequence, then calculate the correlation coefficient $\eta_{jt}^{(x)}$. After calculating we got

$$\eta_X = \begin{bmatrix} \eta_{11}^{(X)} & \eta_{12}^{(X)} & \cdots & \eta_{1m}^{(X)} \\ \eta_{21}^{(X)} & \eta_{22}^{(X)} & \cdots & \eta_{2m}^{(X)} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{n1}^{(X)} & \eta_{n2}^{(X)} & \cdots & \eta_{nm}^{(X)} \end{bmatrix} \tag{6}$$

where, the $\eta_{jt}^{(x)}$ (i=1, 2, …, m, j=1, 2, …, n) is the correlation coefficient or Superior degree of the evaluated companies $P^{(j)}$ on the terms of index X_i. Therefore, we set it as Membership of Fuzzy Sets (named $f(x_i)$), and set $\eta_{jt}^{(x)}=r_{ij}^{(x)}$.

So far, we have got the membership $r_{ij}^{(x)}$ (where i=1, 2, …, m, j=1, 2, …, n) of evaluated companies, and we got the Fuzzy evaluation matrix transfer from U_x to P .

$$R_X = \begin{bmatrix} r_{11}^{(X)} & r_{12}^{(X)} & \cdots & r_{1n}^{(X)} \\ r_{21}^{(X)} & r_{22}^{(X)} & \cdots & r_{2n}^{(X)} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1}^{(X)} & r_{m2}^{(X)} & \cdots & r_{mn}^{(X)} \end{bmatrix} = \begin{bmatrix} \eta_{11}^{(X)} & \eta_{12}^{(X)} & \cdots & \eta_{1m}^{(X)} \\ \eta_{21}^{(X)} & \eta_{22}^{(X)} & \cdots & \eta_{2m}^{(X)} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{n1}^{(X)} & \eta_{n2}^{(X)} & \cdots & \eta_{nm}^{(X)} \end{bmatrix}^T \tag{7}$$

Similarly, we get R_y that transfer from U_Y to P ; R_Z that transfer from U_Z to P ; R from U to P.

2.4 Two levels of Grey Correlation Degree - Fuzzy Comprehensive Evaluation Model

By using $A_x=(a_1^{(x)}, a_2^{(x)},\dots, a_m^{(x)})$ and R_x we can generated a Fuzzy Comprehensive Evaluation Model, symbol as B_x, where $B_x=(b_x^{(1)}, b_x^{(2)},\dots, b_x^{(n)})=A_x\cdot R_x$.

We set B_x as evaluation vectors of N evaluated companies .and $b_x^{(j)}$ is the index of the first class index X (Innovation Opportunity Recognition Capability) of a company.

Similarly, we get B_y and B_Z respectively stand for the first class index Y (Innovation Process Execution Capability) and the first class index Z (Innovation Result Evaluation Capability) of a company.

$B_Y=(b_Y^{(1)}, b_Y^{(2)},\dots, b_Y^{(n)})= A_Y\cdot R_Y$

$B_Z=(b_Z^{(1)}, b_Z^{(2)},\dots, b_Z^{(n)})= A_Z\cdot R_Z$

$B=(b_1, b_s,\dots, b_n)=A\cdot R$

3. Results and Discussion

3.1 Data sources and statistical description

We investigated 60 companies by filling out the questionnaire, which including state-owned enterprises, collective enterprises, private enterprises, joint ventures, foreign-funded enterprises and various businesses of all sizes, which located in Beijing, Tianjin, Shanghai, Hebei, Jiangsu and other provinces in China, and which involve many industries, such as automobile industry, electronics, household appliances, heavy machinery, electrical equipment, plastic products, instruments, metallurgy, cement, chemical, pharmaceutical, tobacco, food processing industry, etc. Among the 60 surveyed companies, there are 27 enterprises implemented servitization strategy, accounting for 45% of the total survey.

Table 1: All levels of the index weight vector

Index X	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
Weight	0.1018	0.1285	0.1340	0.1308	0.1264	0.1301	0.1161	0.1322
Index Y	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
Weight	0.1230	0.1310	0.1342	0.1106	0.1206	0.1299	0.1223	0.1285
Index Z	z_1	z_2	z_3	z_4	z_5	z_6		
Weight	0.1457	0.1838	0.1805	0.1799	0.1807	0.1294		
Indicates	X	Y	Z					
Weight	0.3303	0.3538	0.3159					

3.2 Data Processing and Analysis

1. Data processing

According to the actual situation of these 60 companies, we endow them score from 0 to 5, these are what all raw data come from, and therefore it does not require non-dimensional processing. We mathematically operate the raw data by using Matlab programming method, and then to obtain weight of index of each underlying system and upper system, we got fuzzy evaluation matrix and the index value as well.

2. The evaluation results

It can be obtained all levels of index weight by operational programming (list in Table 1). Because of the large data of fuzzy evaluation matrix and results, we do not list all the data in the article, but show them in Figure 2.

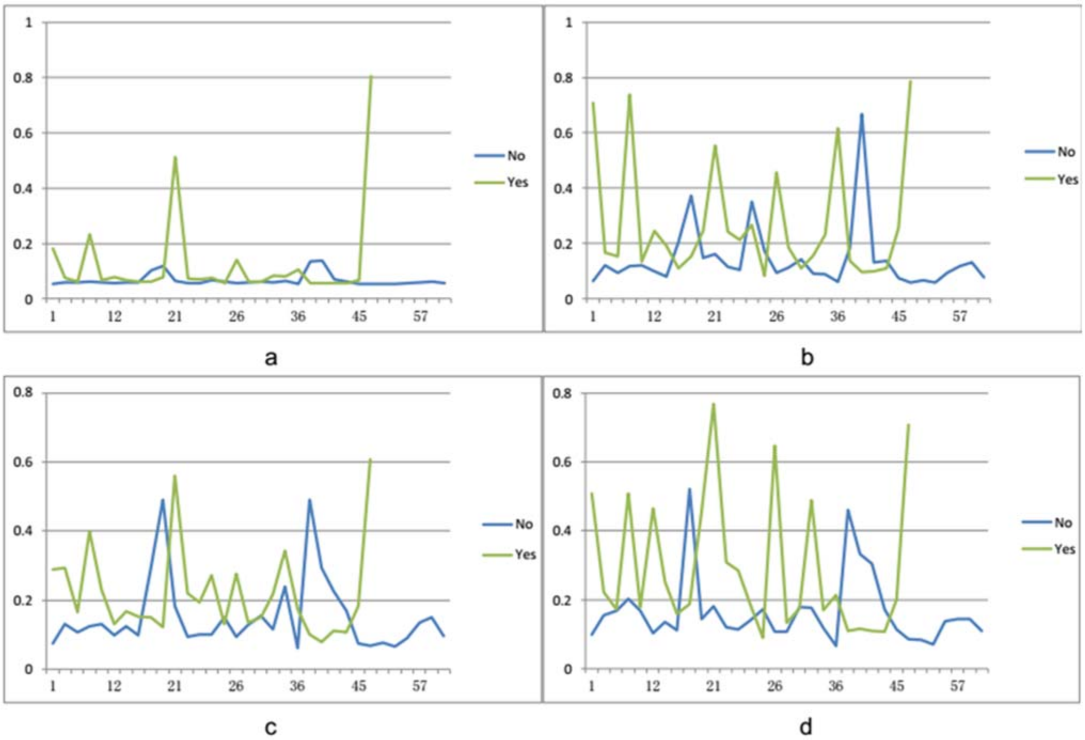

Figure 2: a-Scatter diagram of innovation opportunity recognition capability index
b- Scatter diagram of innovation process execution capability index
c- Scatter diagram of innovation result evaluation capability index
d- Scatter diagram of enterprise innovation capability comprehensive index

3. The analysis of evaluation results

In Figure2, “Yes” means the companies which have taken manufacturing strategy of servitization, “No” means the companies which have not. From figure 2a, we can clearly see that companies which have taken manufacturing servitization strategy get higher index on Innovation Opportunity Recognition Capability (average index: 0.2758) than those haven’t taken manufacturing servitization strategy (average index: 0.1430). And the similar results which can be seen from Figure 2b, 2c. Thus, it can be concluded that the manufacturing servitization has a promotion effect on enhancing the Innovation Opportunity Recognition Capability, the Innovation Process Execution Capability, and the Innovation Result Evaluation Capability. From figure 2d, we can clearly see that companies which have taken manufacturing servitization strategy get higher index on the comprehensive capability of enterprise innovation (average index: 0.1258) than those haven’t taken manufacturing servitization strategy (average index: 0.0672). Thus we can know that the manufacturing servitization has a promotion effect on promoting the comprehensive capability of enterprise innovation.

4. Conclusion

Firstly, enterprises developed unbalanced in the three capabilities, some enterprises have strong capability in certain aspects, but not in others. Secondly, the impact of servitization on innovation opportunity recognition capability, innovation result evaluation capability is more obvious, the impact on enterprise innovation process execution capability is relatively weak, and the impact of the enterprise innovation comprehensive capability is also obvious.

Thirdly, manufacturing servitizations has become a clear trend in the development of the global manufacturing industry. The empirical study also proves its important role in enterprises' development. Therefore, manufacturing enterprises should seize the opportunity combined with industry environment, product characteristics and customer demand and other factors to expand the service business.

We hopes the research can provide some reference value in making developing innovative strategies, and policies for enterprises and some relevant government departments.

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Reference

George B., 2004, A model for multiple brand choice, European Journal of Operational Research, 154(1),144-149, DOI:10.1016/S0377-2217(02)00654-9.

Han M.H., Wang L.M., 2015, Studies on internal and external factors of collaborative innovation and their operational mechanism among small and medium sized enterprises (smes), Chemical Engineering Transactions, 46, 439-444, DOI: 10.3303/CET1546074.

Joseph A. S., 1982, The theory of economic development, Transaction Publishers, Piscataway, New Jersey US.

Li M.Z., Gu X.M., Zhao Y.J., 2015, Research on enterprise innovation performance based on dea and sna, Chemical Engineering Transactions, 46, 1273-1278, DOI: 10.3303/CET1546213.

Liu X.l., 2000, Fourth generation R&D: the tool for mastering discontinuous innovation, China Industrial Economics, 09, 53-58.DOI:10.3969/j.issn.1006-480X.2000.09.009.

Liu Y., 2007, The research on synthetic evaluation of science and technology development level based on various regions of China, Master's degree thesis of Jiangsu University, Zhenjiang, China.

Sun X.M., Zhao M., Chen J.S., 2010, Empirical research of knowledge-intensive enterprises technical innovation capability evaluation, Journal of Wuhan Institute of Technology, 32(2), 1-4, DOI: 10.3969/ j .issn.1674-2869 .2010 .02.001.

Yang D.Q., 2001, System optimization research on elements forming product innovation competence of enterprise, Doctoral dissertation of Harbin Engineering University, Harbin, China.

Zheng C.D., He J.S., 2000, A new method for the evaluation of technological innovation capability of enterprises, Science and technology management research, 03, 41-44.