Design Engineering

ISSN: 0011-9342

Issue: 11 | Pages: 848 - 885

How Effective is Manufacturing Transformation and Upgrading? A Case Study of China

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Abstract:

Owing to internal worries and external challenges, the manufacturing transformation and upgrading (MTU) has become the top priority for China to achieve sustainable economic development. Many policies have been issued to promote the MTU. To evaluate the effectiveness of China's MTU, this study defines the MTU's connotation and constructs a five-dimensional evaluation system, including power conversion, structure optimization, industrial benefit, ecological benefit, and social contribution. With the compound correlation entropy matter element model and data of eight representative manufacturing countries and thirty-one provinces of China from 2001 to 2015, the effectiveness of China's MTU is analyzed from aspects of development stages, international comparison, and provincial comparison. Results show that China's MTU has experienced three stages - inhibition period, slow development period, and rapid development period. Although its effectiveness has been greatly improved, it is far from success. There is still a large gap in MTU between China and other representative manufacturing countries. Shortcomings of China's MTU can be divided into three types. Among them, defects of slow green manufacturing transformation and low added value of products are particularly serious. Besides, thirty-one provinces of China can be divided into

five echelons according to the effectiveness of MTU.

***Keywords**: Manufacturing transformation and upgrading, Effectiveness evaluation, China, The compound correlation entropy matter element model.*

I. INTRODUCTION

Over the past more than 40 years, China has achievedfast expansion in the manufacturing industry due to its merits of cheap labor and abundant resources and has gradually become the world's largest manufacturing country. Its manufacturing scale has ranked first in the world for ten consecutive years since 2010 [1]. In 2018, its manufacturing added value exceeded US $4 trillion, contributing about 30% of manufacturing output value in the world and 87% of industrial output value in China. However, the development mode focusing on speed and neglecting quality has caused the manufacturing industry of China to be "big but not strong", with problems such as insufficient core technology, weak leading enterprises, poor industrial structure, and low-end lock-in on the value chain [2,3]. Besides, with the depletion of resources and deterioration of the environment, the traditional extensive mode of production has also caused China to face huge pressure of resources and environment, serious overcapacity, and other problems, which severely restricts its sustainable development of manufacturing industry [4]. According to the 2016 World Environmental Performance Index Report issued by Yale University and other units, the environmental performance of Chinais second to last among 180 countries [5]. The industrial issue of “big but not strong” and the heavy pressure on the resources and environment become China's internal worries about the sustainable growth of the manufacturing industry.

The international financial crisis in 2008 heavily damaged the world economy. After that, some major industrialized countries realized the importance of the real economy. They began to re-emphasize the development of manufacturing and seek new momentum for economic growth by transforming and upgrading the manufacturing industry [6]. In 2009, the United States first proposed to upgradethe manufacturing structure based on the advantages of intellectual property rights in the "National Strategic Plan for Advanced Manufacturing Industry". Then, the German, in 2013, formally established the national strategy of"Industry 4.0" enabling the rapid development of intelligent manufacturing [7,8]. Japan, Britain, France, South Korea, and other countries also introduced strategies to revive the manufacturing industry to seize the opportunity in the new round of technological reformation [9,10]. A new generation of the industrial revolution is quietly rising [11]. At the same time, with the disappearance of the demographic dividend, manufacturing and production costs in China gradually increase. Emerging economies

ISSN: 0011-9342

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represented by Southeast Asia and India take advantage of their lower labor and resource costs and actively undertake the transfer of low value-added labor-intensive industries, resulting in serious migration of China’s manufacturing industry [12]. "Made in China" is increasingly being replaced by "Made in Vietnam" and "Made in Indonesia". The return of high-end manufacturing to developed countries and the diversion of low-end manufacturing to emerging economies bring dual external squeezes to China's manufacturing industry.

In this context, manufacturing transformation and upgrading (MTU) becomes the top priority for China to actively respond to the internal worries and external challenges and achieve sustainable development. Many policies related to this were proposed. As early as 1994, the government has released the "China's agenda 21: White Paper on China's Population, Environment and Development in the 21st Century"for sustainable development[13]. After that, as the industrialization and urbanization speed up, China continues to enrich the connotation of sustainable development, actively explores new industrialization paths, and regards the growth of strategic emerging industries,the improvement of industrial structure, and the transformation and upgrading of traditional industries as important ways to achieve sustainable development of the industry. In 2005, China approved the “Several Opinions of the State Council on Accelerating the Development of the Recycling Economy”, emphasizing that it would vigorously develop high-tech industries, strengthenthe transformation of traditional industries and eliminate outdated processes, technologies, and equipment [14]. In 2007, the report of the 17th National Congress of the Communist Party of China put forward the integration of industrialization and informatization, taking advantage of the effect of "1 + 1> 2" to promote the development of new industrialization. In 2010, the "Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries" set energy conservation and environmental protection as one of the development directions of strategic emerging industries. In 2015, China comprehensively implemented the strategy of "Made in China 2025", aiming to accelerate the manufacturing transformation and upgrading and make China a great power in manufacturing [15].In 2016, Chinaissued the "Thirteenth Five-Year Plan", which indicated that efforts should be made to carry out the supply-side structural reforms, helping to upgrade the industrial structure and push the manufacturing industry to develop in directions of intelligent,high-end, green and service-oriented [16].

These policies have affected China’s MTU to a large degree. But so far, there are still many unsolved problems: What are the criteria for a successful MTU? What stages have China’s MTU undergone? Has China's MTU been successful now? What are the shortcomings of China’s MTU? These problems are extremely significant for China’s MTU, but scholars have ignored them and no one has ever done a research about them. To solve these problems, this study reasonably defines the connotation of MTU and constructs a five-dimensional evaluation index system to comprehensively measure the effectiveness of the MTU. With the compound correlation entropy matter element model and data of 8 representative manufacturing countries and 31 provinces of China from 2001 to 2015, the effectiveness of China's MTU is deeply analyzed from three aspects - development stages, international comparison, and provincial comparison. Besides, the criteria for a successful MTU and China's current shortcomings are clarified. Conclusions and suggestions for improving China's effectiveness of MTU are proposed. These have great reference value for academia to comprehensively and deeply understand the MTU, and for the country to formulate manufacturingstrategies and plans to achieve sustainable growth.

II. CONNOTATION OF MANUFACTURING TRANSFORMATION AND UPGRADING

Currently, the connotation of MTU has not been unified. Scholars mainly analyze it from five aspects.

The first aspect is industrial production methods and product added value. Pietrobelli and Rabellotti [17] regarded MTU as the ability to produce better products, adopt more efficient production methods, or transforminto higher-skilled activities. Mao Yunshi and Wu Yao [18] thought that the value chain control was the key to the success of MTU, and put forward five standards such as the enhancement of product functions and the increase in the technological content and the added value of the product. Xu Xiaohuan [19] measured MTU by the degree to which the manufacturing industry was embedded in the global value chain.

The second aspect is manufacturing economic benefits and development momentum. Chu Xiaohua [20], Zhang Chengli [21] believed that MTU referred to the improvement of industrial development ability, industrial profitability, and industrial debt-paying ability.

The third aspect is technological upgrading and structural optimization. Tang Xinjie [22] proposed that MTU included two parts: manufacturing transformation and manufacturing upgrading. The former referred to the transformation activities aimed at improving production efficiency and material utilization rates, such as technical updates and equipment upgrades. The latter referred to the rise of manufacturing in both ends of the value chain, that is, servitization of manufacturing. Wang Zhihua [23] usedthe technology-intensive level, the large-scale level,the ecological level, the high value-added level, and the high processing level of heavy industries to measure the transformation and upgrading of structure. Zhang Xianhui [2] analyzed the revelation of the industry 4.0 to China and indicated that enhancing core technologies and

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adjusting industrial structure are important factors enabling China to make necessary manufacturing transformation and upgrading.

The fourth aspect is the industrial impact on the environment. Ai Mingye [24] analyzed MTU mainly according to carbon emissions and their intensity. On this basis, Sun Lijun and Yan Liang [25] expanded the analysis scope to the improvement of the manufacturing ecological level.

In addition to the above aspects, based on the industrial economics theory, Hu Chi [26] proposed that when measuring MTU from a dynamic perspective, both the process and the effects needed to be measured. He analyzed MTU from five dimensions, including the proportion of service industry, industrial restructuring, energy saving, labor productivity, and R & D investment. Li Lianshui [27] expounded the connotation of the “new type” of the manufacturing industry from the aspects of technological innovation ability,economic creativity ability, environmental protection ability, energy saving ability, and social service ability. That research also provides a great reference for this study.

Based on the above views, this study defines the connotation of MTU as follows: MTU refers to the process that based on the current industrial strategic planning and industrial development foundation, subject to resource and environmental constraints, main bodies of the manufacturing industry change the mode of production from the extensive type with high input, high consumption, high pollution, and low efficiency to the intensive type with low input, low consumption, low pollution, and high efficiency, drive products to climb from the low value-added position to the high value-added position in the value chain, optimize industrial structure from the labor-intensive one to the technology-intensive one through technological innovation and structural adjustment, and finally realize the improvement of manufacturing benefits. According to the connotation, MTU includes five dimensions: the conversion of development power, the optimization of industrial structure, the promotion of industrial benefit, the improvement of ecological environment, and the increase of social contribution.

III. CONSTRUCTION OF EVALUATION INDEX SYSTEM FOR THE EFFECTIVENESS OF MANUFACTURING TRANSFORMATION AND UPGRADING

Based on the principles of systematization, scientificity, pertinence, and maneuverability, a set of index system is constructed to comprehensively evaluate the effectiveness of MTU. It includes 5 first-level indicators, 11 secondary indicators, and 31 tertiary indicators, shown in Table 1. The first-level indicators are power conversion, structural optimization, industrial benefit, ecological benefit, and social contribution, selected according to the five-dimensional

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connotation of MTU. The secondary and tertiary indicators are selected by the literature high-frequency method.

(1)Power conversion

The power conversion effectiveness indicates the transformation level that manufacturing entities have achieved from investment-led and factor-driven to knowledge-led and innovation-driven by changing production methods and implementing technological innovation. Drawing on the practice of scholars from the Guangdong Academy of Social Sciences [28], this study uses innovation support level and financial support strength to evaluate the power conversion effectiveness. The former is measured by D1, D2, D3, D4, and D5. The latter is measured by D6.

(2) Structure optimization

The structural optimization effectiveness is mainly used to measure the structural optimization level of the manufacturing industry. It is evaluated by three secondary indicators - industry structure [26], product structure [17], and trade structure [29]. The industry structure is reflected by D7, D8, D9, and D10. The product structure is reflected D11 and D12. The trade structure is reflected by D13.

(3) Industrial benefit

The industrial benefit improvement effectiveness is mainly used to measure the promotion level of the industrial development capacity during the process of MTU. It is evaluated by two secondary indicators - production efficiency [16, 18] and innovation benefit [27]. The former is evaluated by D14, D15, D16, and D17. The latter is evaluated by D18, D19, D20, D21, and D22.

(4) Ecological benefit

From the connotation of MTU, it can be seen that the manufacturing industry needs to develop from the resource-led and extensive one to the intensive and connotative one. The ecological benefit improvement effectiveness is used to measure the effectiveness of green manufacturing change and the improvement level of the resource and environment brought by MTU. It is evaluated by two secondary indicators - energy consumption level and environmental protection level [25, 27]. The energy consumption level is measured by D23 and D24. The environmental protection level is measured by D25, D26, and D27.

(5) Social contribution

The social contribution effectiveness is mainly used to reflect the role of MTU in promoting the development of social systems such as employment and taxation. There are two secondary indicators in this dimension - tax contribution level and employment absorption level [23, 25, 31]. The tax contribution level is reflected by D28 and D29. The employment absorption level is reflected by D30 and D31.

TABLE I. The evaluation index system for the effectiveness of manufacturing transformation and upgrading (MTU)

First-level indicators	Secondary indicators	Tertiary indicators	Indicator description	Units
Power conversion	Innovation support level (C1)	Manufacturing R & D expenditure(D1)	Total R & D expenditure of all manufacturing enterprises	Ten thousand yuan
		R & D funding input intensity(D2)	R & D funding input /GDP * 100%	%
		Full-time equivalent of manufacturing R & D personnel(D3)	Sum of the full-time equivalent of R &D personnel in manufacturing industry	Man-year
		Innovation talent input intensity (D4)	Number of R & D personnel / number of employees * 100%	%
		Expenditure for new product development (D5)	Expenditure on new product development of manufacturing industry	Ten thousand yuan
	Financial support strength (C2)	Level of government financial support (D6)	Total government expenditure / GDP * 100%	%

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Structure optimization	Industry structure (C3)	Proportion of output value of capital-intensive and technology-intensive manufacturing industry (D7)	Output value of capital-intensive and technology-intensive manufacturing industry / output value of manufacturing industry * 100%	%
		Proportion of high-tech enterprises (D8)	Number of high-tech enterprises / number of manufacturing enterprises	Unit
		Manufacturing product sales rate (D9)	Manufacturing product sales revenue / total manufacturing output value * 100%	%
		Proportion of manufacturing enterprises with R & D activities (D10)	Number of enterprises with R & D activities / Total number of manufacturing enterprises * 100%	%
	Product structure (C4)	Proportion of high value-added products' output (D11)	Output of high value-added products / total output of industrial products * 100%	%
		Product contribution value rate (D12)	(Output value of products - investment in fixed assets) / investment in fixed assets * 100%	%
	Trade structure (C5)	Revealed comparative advantage index (D13)	China's manufacturing export proportion / world manufacturing export proportion * 100%	%

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Industrial benefit	Production efficiency (C6)	Manufacturing value added rate(D14)	Manufacturing value added / total manufacturing output * 100%	%
		Manufacturing total labor productivity (D15)	Total manufacturing output / number of employees in manufacturing	100 million yuan / person
		Manufacturing output intensity (D16)	Gross output value / area of built-up areas	100 million yuan / thousand hectares
		Manufacturing profit margins (D17)	Total profit / main business income * 100%	%
	Innovation benefit C7)	Number of patent applications (D18)	Total number of patent applications for manufacturing industry	Piece
		Number of valid invention patents (D19)	Total number of effective inventions for all manufacturing	Unit
		Number of patents granted(D20)	Total number of patents granted for all manufacturing	Unit
		Rate of new product output value (D21)	Manufacturing new product output value / manufacturing total output value * 100%	%
		Manufacturing innovation input-output coefficient (D22)	New product output value / new product development expenditure * 100%	%

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Ecological benefit	Energy consumption level (C8)	Output value of unit energy consumption (D23)	Gross output value / total energy consumption	100 million yuan / 10,000 tons of standard coal
		Output value of three wastes comprehensive utilization products (D24)	Total output value of three waste comprehensive utilization products in manufacturing industry	Ten thousand yuan
	Environmental protection level (C9)	Unit emission (waste water) output value (D25)	Total output value / total wastewater emissions	100 million yuan / 10,000 tons
		Unit emission (waste gas) output value (D26)	Total output value / total exhaust emissions	100 million yuan / 100 million cubic meters
		Unit emission (solid waste) output value (D27)	Total output value / total solid waste emissions	100 million yuan / ton
Social contribution	Tax contributionlevel (C10)	Total profits and taxes of manufacturing enterprises (D28)	Total profits and taxes of all manufacturing enterprises	100 million yuan
		Profits and taxes rate of manufacturing output value (D29)	Total profits and taxes of manufacturing industry / total output value of manufacturing industry	%
	Employment absorption level (C11)	Proportion of manufacturing employees(D30)	Employment in manufacturing industry / total population of China	%
		Wage level of manufacturing employees (D31)	Average wage of employees in manufacturing enterprises	Yuan

IV. CONFIRMATION OF EVALUATION MODEL FOR THE EFFECTIVENESS OF MANUFACTURING TRANSFORMATION AND UPGRADING

By integrating the correlation method in the gray system, the matter element analysis method in the field of extenics, and the entropy method, this study builds a compound correlation entropy matter element model to evaluate the effectiveness of MTU. Through the comprehensive improvement and integration of multiple methods, the scientificity and objectivity of the model are greatly improved. The model construction process is as follows.

4.1 Construction of Compound Matter Element

Matter element refers to an ordered triple containing the name, features, and values of a thing. Define a matter *M*, having features of *C* with corresponding values of *X*, then the basic expression of the matter element is $R = [M, C, X]$. If the values are uncertain, then *M* is called entropy matter element. If the matter *M* has *n* features and corresponding values, then the matter element is called n-dimensional compound matter element, recorded as R_{mn}.

$$R_{mn} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ C_1 & x_{11} & x_{21} & \cdots & x_{m1} \\ C_2 & x_{12} & x_{22} & \cdots & x_{m2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where M_i represents the i^{th}sample, C_j is the j^{th}measurement indicator, and the corresponding value of the i^{th} sample's j^{th} measurement indicator is represented by X_{ij}. As the evaluation index system has 31 tertiary indicators, when evaluating the effectiveness of China's MTU from 2001 to 2015, *m* is 15 and *n* is 31, and when evaluating the effectiveness of transformation and upgrading in China's 31 provinces, *m* is 31 and *n* is 31.

4.2 Normalization of the Indicators' Data

To eliminate the impact caused by the different scale of features, this study normalizes the data with the method of min-max normalization. Indicators involved in the evaluation system can be divided into benefit type and cost type. In this study, D1, D3, D5, D8, D15, D16, D18, D19, D20, D23, D24, D25, D26, D27, D28, D31are regarded as cost indicators, and the remaining ones are regarded as benefit indicators. Assume $J^+ = \{\text{benefit indicators}\}$, $J^- = \{\text{cost indicators}\}$, for benefit indicators, use formula (2) for normalization, and for cost indicators, use formula (3).

$$\mu_{ij} = \left(x_{ij} - \min_{1\le i\le n} x_{ij}\right) \Big/ \left(\max_{1\le i\le n} x_{ij} - \min_{1\le i\le n} x_{ij}\right), \left(i = 1,2,\cdots,n; j \in J^+\right) \quad (2)$$

$$\mu_{ij} = \left(\max_{1\le i\le n} x_{ij} - x_{ij}\right) \Big/ \left(\max_{1\le i\le n} x_{ij} - \min_{1\le i\le n} x_{ij}\right), \left(i = 1,2,\cdots,n; j \in J^-\right) \quad (3)$$

Where x_{ij}indicates the i^{th} sample's j^{th} measurement indicator, u_{ij} is the value of x_{ij} after normalization, n is the total number of samples.

Then, the normalized R_{mn} is:

$$\underset{\sim mn}{R} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ C_1 & \mu_{11} & \mu_{21} & \cdots & \mu_{m1} \\ C_2 & \mu_{12} & \mu_{22} & \cdots & \mu_{m2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & \mu_{1n} & \mu_{2n} & \cdots & \mu_{mn} \end{bmatrix} \quad (4)$$

4.3 Determination of Indicators' Weight

The weight of the evaluation indicators in each dimension will directly affect the evaluation results. To ensure the objectiveness and correctness of results, the correlation entropy method is adopted to calculate the weight of every indicator. This method uses entropy to measure the amount of information. It is believed that the greater the differences in the values of an indicator, the more influence this indicator will have on the system, that is, the more information this indicator contains and transmits, the less entropy it will have, and therefore the more weight the indicator should be given. Steps calculating indicators' weight are as follows:

Firstly, determine the grey correlation coefficient $\underset{\sim mn}{R}$. Establish a reference sequence $Y_0 = \{y_1, y_2, \cdots, y_n\}^T$, ($y_j = \max_{1 \le i \le m} \mu_{ij}, j = 1, 2, \cdots, n$). The comparison sequence and the reference sequence together constitute a gray correlation factor set, $@\,GRF = \left[Y_0 \ \underset{\sim mn}{R} \right]$, and the difference sequence $\Delta_i = \left| Y_0 - Y_i \right|$ is obtained. Then, the gray correlation coefficient of C_j, the j^{th}measurement indicator of $\underset{\sim mn}{R}$, can be expressed as:

$$\zeta_{ij} = \frac{\min_i \min_j \Delta_i + \rho \max_i \max_j \Delta_i}{\left| \mu_{ij} - y_j \right| + \rho \max_i \max_j \Delta_i} \quad (5)$$

Where ρ is the resolution factor. To reduce the distortion of the correlation coefficient of the measurement indicator caused by the excessive maximum absolute difference, the value of ρ is usually set to 0.5.

Secondly, work out the entropy of every indicator. The entropy of C_j is:

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$$F_j = -(\ln m)^{-1}\sum_{i=1}^{m}\frac{\zeta_{ij}}{\sum_{ij}^{m}\zeta_{ij}}\ln\frac{\zeta_{ij}}{\sum_{i=1}^{m}\zeta_{ij}},(i=1,2,\cdots,m;j=1,2,\cdots,n)\quad(6)$$

Thirdly, calculate the weight of every indicator.The degree of deviation is obtained by $k_j = 1 - F_j$, then the weight of C_j can be expressed as:

$$w_j = k_j \Big/ \sum_{j=1}^{n} k_j \quad (7)$$

The compound matter element for the indicators' weight is constructed as:

$$R_{wj} = \begin{bmatrix} & C_1 & C_2 & \cdots & C_n \\ w_j & w_1 & w_2 & \cdots & w_n \end{bmatrix} \quad (8)$$

4.4 Determination of the Compound Correlation Entropy Matter Element

$\underset{\sim mn}{R}$ and R_{wj} constitute $\underset{\sim mH}{R}$, which is the compound correlation entropy matter element of the effectiveness of MTU with *m* samples. $\underset{\sim mH}{R}$ is expressed as:

$$\underset{\sim mH}{R} = \begin{bmatrix} & M_1 & M_2 & \cdots & M_m \\ H_i & H_1 & H_2 & \cdots & H_m \end{bmatrix}$$
$$= \begin{bmatrix} & M_1 & \cdots & M_i & \cdots & M_m \\ H_i & -\sum_{j=1}^{n}P(w_j\mu_{1j})\ln P(w_j\mu_{1j}) & \cdots & -\sum_{j=1}^{n}P(w_j\mu_{ij})\ln P(w_j\mu_{ij}) & \cdots & -\sum_{j=1}^{n}P(w_j\mu_{mj})\ln P(w_j\mu_{mj}) \end{bmatrix} \quad (9)$$

Where $P(w_j\mu_{1j}) = w_j\mu_{ij} \Big/ \sum_{j=1}^{n} w_j\mu_{ij}, i=1,2,\cdots,m; j=1,2,\cdots n$, H_i is the indicator of MTU of the i^{th} sample.

V. MEASUREMENT AND ANALYSIS OF THE EFFECTIVENESS OF MANUFACTURING TRANSFORMATION AND UPGRADING

5.1 Development Stages of the Effectiveness of China's Manufacturing Transformation and Upgrading

To know the development stages and future trend of China's MTU, this study calculates the effectiveness of China's MTU from 2001 to 2015 based on the evaluation index system of Table 1 and the compound correlation entropy matter element model. The data was obtained from the

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China Industry Statistical Yearbook, China Statistical Yearbook, andChina Statistical Yearbook of Science and Technology. The results can be seen in Table 2.

TABLE II. The effectiveness of China's MTU from 2001 to 2015

Year	Power conversion	Structural optimization	Industrial benefit	Ecological benefit	Social contribution	Overall effectiveness
2001	0.3010	0.1703	0.4076	0.3333	0.3683	0.4725
2002	0.3066	0.1568	0.4238	0.3395	0.3754	0.4399
2003	0.3037	0.1337	0.4374	0.3477	0.3551	0.4059
2004	0.3175	0.1028	0.4904	0.3724	0.3655	0.3696
2005	0.3243	0.0975	0.4127	0.3837	0.4029	0.3282
2006	0.3401	0.1710	0.4333	0.4062	0.4470	0.3518
2007	0.3605	0.1543	0.4637	0.4453	0.4264	0.3586
2008	0.4087	0.1575	0.4870	0.5088	0.4247	0.3686
2009	0.4537	0.2149	0.4830	0.5888	0.5594	0.3974
2010	0.4553	0.2153	0.5540	0.7113	0.5332	0.4297
2011	0.5648	0.2392	0.5633	0.5981	0.5343	0.4390
2012	0.6739	0.3109	0.5691	0.6114	0.6190	0.4659
2013	0.7474	0.4907	0.6125	0.6599	0.8196	0.5189
2014	0.8524	0.6038	0.6979	0.6886	0.8567	0.5680
2015	0.8422	0.7291	0.8328	0.8953	0.8767	0.6336

ISSN: 0011-9342

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To make the results more intuitive and clear, the overall effectiveness and the effectiveness in five subdivision dimensions - power conversion, structural optimization, industrial benefit, ecological benefit, and social contribution are further shown in Figures 1 and 2.

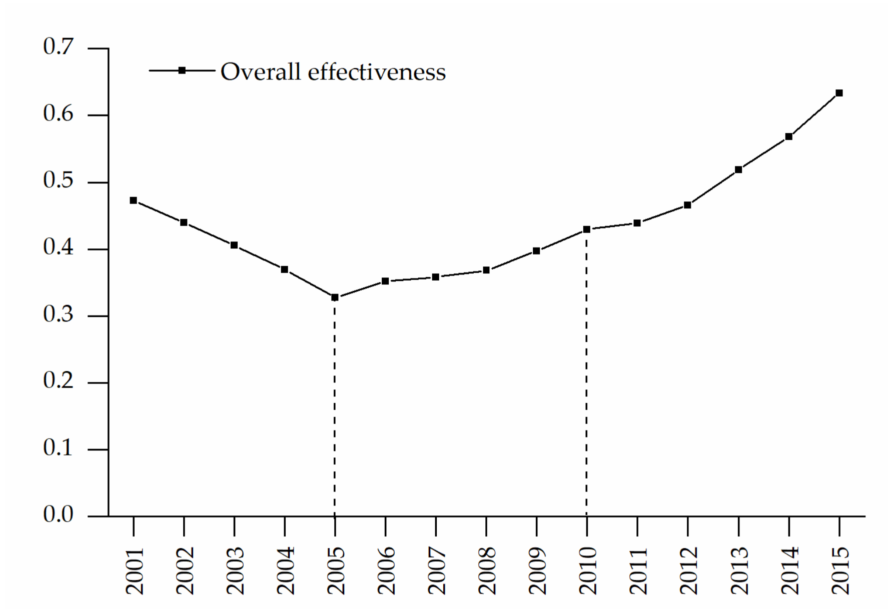

Fig 1: The overall effectiveness of China's MTU

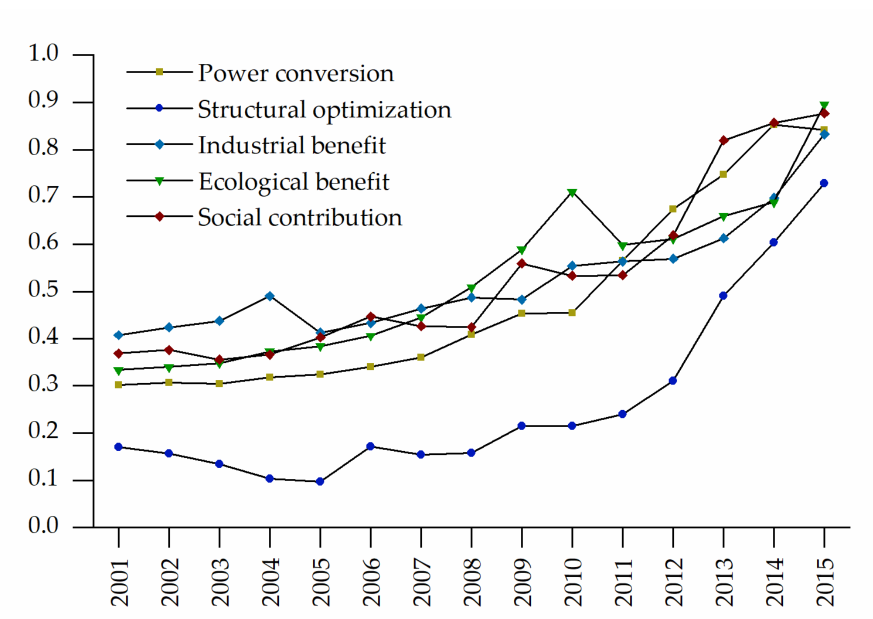

Fig 2: The effectiveness in five sub-dimensions of China's MTU

According to the above results, China's MTU has experienced three stages.

Stage 1, from 2001 to 2005, is the inhibition period of MTU. The overall effectiveness of China's MTU declined significantly year by year, which had a lot to do with the economic development priorities of China's 10th Five-year Plan. During this period, China conducted the 10th Five-Year Plan, which was the first economic plan implemented in the context of globalization. China's economic breakthroughs mainly depended on its rapid integration into international markets. Due to the advantages of cheap labor and abundant resources, China gradually became a transfer zone of low-end industries in the value chain for western developed countries. The development of its manufacturing industry was mainly based on the production and manufacturing mode of docking with the low-end industrial chain of the international market to manufacture large quantities of low value-added products. By the end of 2005, China's labor-intensive manufacturing industries accounted for 89.53% of the total manufacturing industries, and the input of innovation factors was extremely insufficient. The R & D funding input intensity of China in manufacturing was only 0.67%, far lower than that of the United States of 2.65%. Such a development model highly depending on low-cost labor and massive resource consumption greatly degraded the manufacturing structure and thus inhibited the MTU. The development of the manufacturing industry in this stage has three features: the factor-driven development model, extremely low product added value and technology content, and low-end industrial structure.

Stage 2, from 2006 to 2010, is the slow development period of MTU. The growth rate of the effectiveness of China's MTU changed from negative to positive, and the effectiveness was slowly improving year by year. Especially after 2008, the financial crisis forced western developed countries to revitalize the manufacturing industry. In this background, China's MTU was promoted and its speed was improved to some degree. Besides, owing to the national strategic deployment of scientific development concept and integration of industrialization and information, the Chinese paid more attention to ecological construction, environmental protection, and industrial sustainable development, which contributed to the increase of the effectiveness of sub-dimensions. It can be seen from the sub-dimensional effectiveness changes that China's manufacturing development mode began to transform from factor-driven to innovation-driven. Technology, talent, and finance gradually replaced demographic dividend, resource advantage, and policy dividend and became the main driving forces for manufacturing development. Relying on power conversion, China's manufacturing structure began to be optimized. The proportion of capital-intensive and technology-intensive manufacturing industry increased from 10.47% in 2005 to 18.66% in 2010. The rapid growth of industrial benefit also improved the role of the manufacturing industry in employment absorption and tax contribution to society.

Stage 3, from 2011 to 2015, is the rapid development period of MTU. China's MTU grew rapidly and achieved high effectiveness. This is mainly due to China's foundation of economic transformation and the emphasis of "made in China 2025" on the MTU. By the end of 2015, the growth rate of the effectiveness of MTU was as high as 11.55%, and the effectiveness of sub-dimensions was also comprehensively improved. At this stage, the speed of power conversion from factor-driven to innovation-driven was accelerated, and the R & D funding input intensity reached 2.83%, increasing by more than four times in ten years. Besides, with the supply-side structural reform and the rapid development of advanced manufacturing, China's manufacturing industry achieved significant results in optimizing its industrial structure. It began to move into a high-end development path. The capital-intensive and technology-intensive manufacturing industry began to occupy a dominant position with a high proportion of 51.98%. Based on the power conversion and industrial structure adjustment, China's manufacturing industry made remarkable progress in transforming to green manufacturing, and its ecological and industrial benefits also increased at an unprecedented rate.

5.2 International Comparison of the Effectiveness of China's Manufacturing Transformation and Upgrading

China's MTU has undergone multiple stages. To know whether it has been successful or not and what are its shortcomings compared with that of the representative manufacturing countries in the world, this study determines the judging criteria for a successful MTU based on the relevant indicator values of those representative manufacturing countries and performs an international comparative analysis of the effectiveness of MTU between China and those countries.

5.2.1 Determination of the Judging Criteria for a Successful Manufacturing Transformation and Upgrading

According to the "2015 China Manufacturing Power Development Index Report" issued by the Chinese Academy of Engineering, the United States, Germany,France,Japan, the United Kingdom, South Korea, and India have achieved the most significant effectiveness in MTU. These countries are the most representative countries in MTU with characteristics of strong industrial scale, optimized industrial structure, good quality and benefit, sustainable development capabilities. Therefore, this study chooses the above seven countries as international benchmarking objects for evaluating China's MTU. As for the comparative analysis of sub-dimensions, considering the representativeness and significance of indicators, this study selects some key indicators for horizontal comparative analysis. According to the weight of each indicator calculated by the compound correlation entropy matter element model and data of

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China's manufacturing industry (shown in Table 3), the first-level indicators of structure optimization, industrial benefit, power conversion, and ecological benefit play an important role. When evaluating the power conversion effectiveness, D2 and D3 representing the innovation support level are key indicators. When evaluating the structural optimization effectiveness, D7 and D12 revealing industry structure and product structure are key indicators. When evaluating industrial benefit effectiveness, D14, D15, D16, D17, and D18 showing manufacturing production efficiency and innovation benefit are key indicators. When evaluating the ecological benefit effectiveness, D23 and D26 reflecting energy consumption level and environmental protection level are key indicators.

TABLE III. The weight of the evaluation indicators for each dimension of China's MTU

First-level indicators	Weight	Secondary indicators	Weight	Tertiary indicators	Weight
Power conversion	0.1985	Innovation support level	0.8647	D1	0.1989
				D2	0.2082
				D3	0.2017
				D4	0.1794
				D5	0.2118
		Financial support strength	0.1353	D6	0.2523
Structure optimization	0.3132	Industry structure	0.2684	D7	0.3475
				D8	0.1667
				D9	0.2036
				D10	0.2823
		Product structure	0.6613	D11	0.1390
				D12	0.8901

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		Trade structure	0.0703	D13	1.0000
Industrial benefit	0.2383	Production efficiency	0.4197	D14	0.2478
				D15	0.2993
				D16	0.2704
				D17	0.1825
		Innovation benefit	0.5803	D18	0.2568
				D19	0.2100
				D20	0.2089
				D21	0.1622
				D22	0.1620
Ecological benefit	0.1387	Energy consumption level	0.4827	D23	0.4236
				D24	0.5764
		Environmental protection level	0.5173	D25	0.2953
				D26	0.4248
				D27	0.2799
Social contribution	0.1114	Tax contributionlevel	0.4508	D28	0.5842
				D29	0.4158
		Employment absorption level	0.5492	D30	0.5820
				D31	0.4180

Given the differences in statistical indicators across countries and the availability of data, the measurement methods of certain key indicators are appropriately adjusted. Manufacturing R & D personnel as a percentage of employees, industrial concentration of the high-tech industry, high-tech product trade competitive advantage index, GDP per unit energy consumption are used instead of D3, D7, D12, D23, respectively. Manufacturing value added is used instead of

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D14 and D16. GDP per unit carbon dioxide emissions is used to instead of D26. The indicators for the international comparison of the effectiveness of MTU are shown in Table 4.

TABLE IV. The indicators for the international comparison of the effectiveness of MTU

First-level indicators	Secondary indicators	Tertiary indicators	Indicator description	Units
Power conversion	Innovation support level (C1')	R & D funding input intensity (D1')	R & D funding input /GDP*100%	%
		Manufacturing R & D personnel as a percentage of employees (D2')	Number of manufacturing R & D personnel/number of employees*100%	%
Structure optimization	Industry structure (C2')	Trade competitive advantage index of high-tech products (D3')	Difference betwwen export value and import value of current domestic high-tech industry product trade / sum of export value and import value of current domestic high-tech industry product trade*100%	%
	Product structure (C3')	Industrial concentration of high-tech industries (D4')	The proportion of sales revenue of the top five domestic enterprises to the total sales revenue of the domestic enterprises of high-tech industries	
Industrial benefit	Production efficiency	Manufacturing value added (D5')	Manufacturing value added	trillion US dollars

	(C4’)	Manufacturing total labor productivity (D6’)	Total manufacturing output / number of employees in manufacturing	billion US dollars / 10,000 people
		Manufacturing profit margins （D7’）	Total profit / main business income*100%	%
	Innovation benefit (C5’)	Number of patent applications （D8’）	Number of patent applications	Ten thousand pieces
Ecological benefit	Energy consumption level (C6’)	GDP per unit energy consumption（D9’）	Total energy consumption / GDP	USD per kg of oil
	Environmental protection level (C7’)	GDP per unit carbon dioxide emissions（D10’）	Total carbon dioxide emissions / GDP	2011 PPP $ of GDP per kg

Referring to the practice of the scholar Xiang Xiaomei of the Guangdong Academy of Social Sciences [28], this study takes 80% of the average levels of the world's representative manufacturing countries as the inflection points, the criteria for judging whether the MTU has been successful. If the value of an indicator is not lower than the inflection point value, it means that the indicator has reached the successful standard of MTU. If the values of all indicators are not lower than the inflection point values, it means that the overall MTU of China has reached the inflection point values, and China’s MTU has been successful.

5.2.2 International Comparison Results of Manufacturing Transformation and Upgrading

The comparison results of various dimensions for the MTU of China and the representative manufacturing countries in the world are shown in Table 5.The data was obtained from the World Bank database, the Organization for Economic Cooperation and Development (OECD) database, the United Nations Industrial Development Organization (UNIDO) database, and the EPS global statistical database.

TABLE V. The international comparison results of various dimensions for MTU

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Indicator \ Country		Year	United States	Japan	Germany	United Kingdom	France	Korea	India	China	China's ranking	inflection point[1]
Power conversion	D1,	2005	2.51	3.03	2.42	1.56	2.04	2.53	0.61	1.31	7	2.05
		2014	2.73	3.40	2.87	1.67	2.28	4.29	0.69	1.99	6	
		Growth rate (%)	8.76	12.21	18.60	7.05	11.76	69.57	13.11	51.91	2	
	D2,	2005	1.45	1.64	1.36	1.29	1.06	1.01	0.048	0.05	7	0.97
		2014	1.75	1.96	1.88	0.82	0.89	1.05	0.16	0.18	7	
		Growth rate (%)	20.69	19.51	38.24	-36.43	-16.04	3.96	233.33	260.00	1	
Structure optimization	D3,	2005	5.32	6.10	6.30	5.29	4.66	5.50	1.62	0.99	8	4.92
		2014	6.32	7.57	7.92	6.95	5.88	7.03	1.42	2.09	7	
		Growth rate (%)	18.80	24.10	25.71	31.38	26.18	27.82	-12.35	111.11	1	
	D4,	2005	0.93	0.90	1.018	0.768	0.839	0.758	0.51	0.52	7	0.67
		2014	0.94	0.91	1.02	0.79	0.84	0.76	0.55	0.56	7	

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		Growth rate (%)	1.08	1.11	0.20	2.86	0.12	0.26	7.84	7.69	2	
Industrial benefit	D5,	2005	1.69	1.03	0.57	0.27	0.27	0.23	0.13	0.73	3	0.94
		2014	2.04	0.96	0.79	0.29	0.29	0.39	0.31	3.18	1	
		Growth rate (%)	20.40	-7.02	37.53	6.66	9.00	69.29	134.44	343.02	1	
	D6,	2005	9.78	9.63	8.55	6.21	5.82	6.13	0.23	0.78	7	6.49
		2014	11.18	11.02	10.21	7.14	7.35	9.22	0.69	2.31	7	
		Growth rate (%)	14.31	14.43	19.42	14.89	26.29	50.41	200	196	2	
	D7,	2005	3.11	2.40	2.93	2.67	2.64	2.89	3.88	3.07	2	2.39
		2014	3.21	2.42	3.18	2.85	2.75	3.12	3.38	2.99	5	
		Growth rate (%)	3.22	0.83	8.53	6.74	4.17	7.96	-12.89	-2.61	7	
	D8,	2005	3.79	2.23	2.42	0.57	0.84	0.52	0.06	0.15	7	1.16
		2014	3.63	1.99	2.19	0.60	0.96	0.67	0.11	0.73	5	
		Growth rate (%)	-4.26	-10.63	-9.49	4.60	13.86	27.37	87.52	391.02	1	
Ecologic	D9	2005	5.65	9.14	8.54	11.27	8.14	4.27	1.55	1.02	8	5.99

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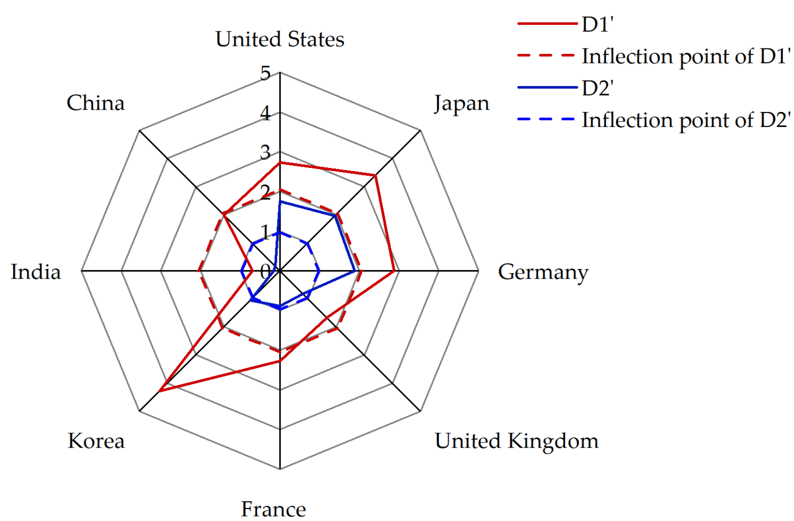
al benefit	’	2014	6.32	8.74	9.40	9.33	7.2	5.58	5.80	4.33	8	
		Growth rate (%)	11.86	-4.38	10.07	-17.21	-11.55	30.68	274.19	324.51	1	
	D10’	2005	2.53	3.68	3.89	4.17	5.95	2.65	3.21	1.26	8	3.67
		2014	3.15	3.92	4.90	5.95	8.20	2.89	3.12	1.69	8	
		Growth rate (%)	24.51	6.52	25.96	42.69	37.82	9.06	-2.80	34.13	3	

[1]The value of inflection point = 2014 average level of the representative manufacturing countries * 80%.

To make the results more intuitive, the comparison results of the effectiveness of MTU and the inflection points in eight countries and four dimensions are further shown in Figure 3.



(a) Power conversion dimension

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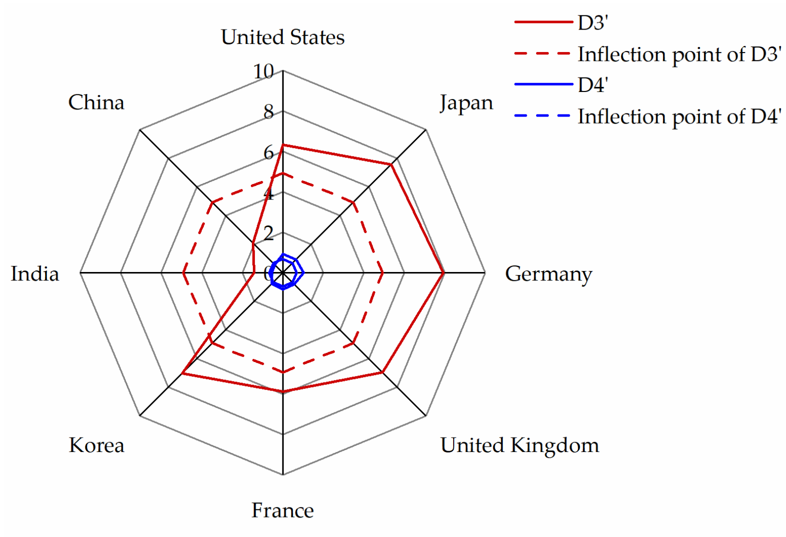
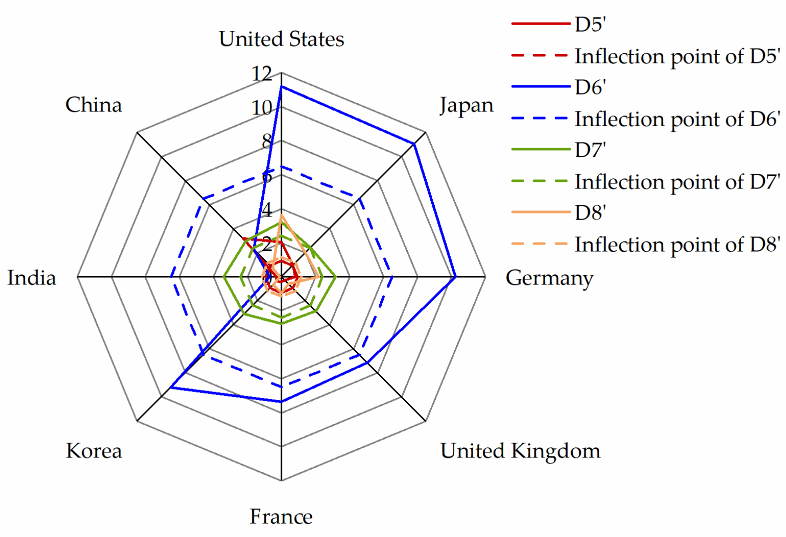
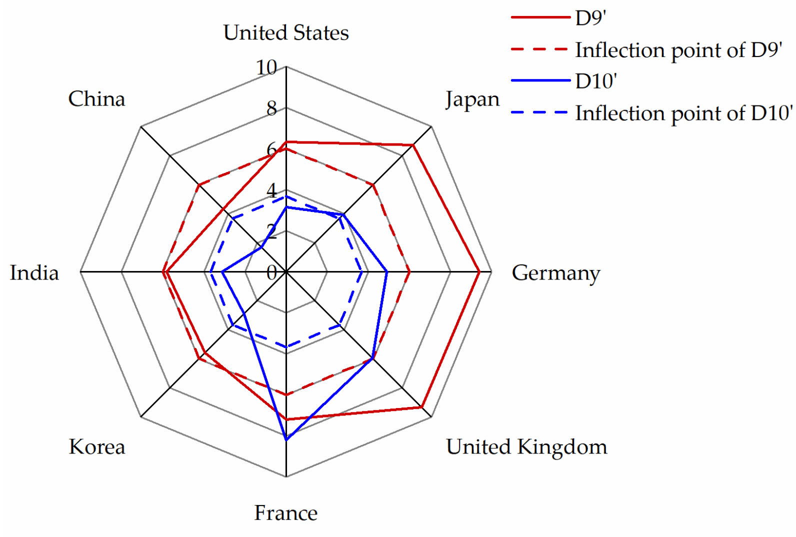


(b) Structural optimization dimension



(c) Industrial benefit dimension



(d) Ecological benefit dimension

Fig 3: The comparison results of the effectiveness of MTU and the inflection points in eight countries and four dimensions

Compared with the representative manufacturing countries, the effectiveness of China's MTU is, as a whole, far from reaching the inflection point values, indicating that the overall MTU of China is far from success. According to the comparison results, except for the manufacturing value added and manufacturing profit margin, the effectiveness values of all other indicators are lower than the inflection point values.

As for the power conversion dimension, China’s R & D funding input intensity was 1.99% in 2014, slightly lower than the inflection point value of 2.05%. The manufacturing R & D personnel as a percentage of employees lagged far behind other countries, even lower than the one-fifth of inflection point value. It can be seen that the innovation funding and talent are both insufficient in the process of China's MTU, and the shortage of the latter is more serious than the former. The insufficient input of innovation factors directly contributes to the lag of manufacturing power conversion.

As for the structure optimization dimension, in terms of product structure, the trade competitive advantage index of high-tech products in 2014 was a bit low, which has not even reached half of the inflection point value. In terms of industrial structure, although China’s industrial concentration of high-tech industries has increased to 0.56 in 2014, close to the inflection point value of 0.67, there is still a large gap between China and other representative

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manufacturing countries. China ranks second to last among the eight countries. The above analysis reflects that unreasonable structure is a problem of China's manufacturing industry. The products are low value-added, the development level of high-tech industries lags behind, and the manufacturing growth path is still locked in the expansion of low-end industries. The manufacturing structure is in a critical period of adjustment and optimization.

As for the industrial benefit dimension, it is the dimension with the best effectiveness in the process of China's MTU. The manufacturing value added and profit margins have reached the standards of the successful MTU. The remaining indicators not reaching the standard also have a relatively fast growth rate. Compared with 2005, the total labor productivity has doubled, and the number of patent applications has increased about 4 timesin 2014. The problems in this dimension mainly focus on the low labor input-output efficiency and low innovation efficiency. Both the total labor productivity and the number of patent applications were far below the inflection point values in 2014. However, with the rapid growth rate, the gap will narrow rapidly.

As for the ecological benefit dimension, it is the dimension with the worst effectiveness in the process of China's MTU. China's energy consumption and environmental pollution are both relatively serious. Especially in terms of environmental pollution, the GDP per unit energy consumption of China is the lowest among the eight countries. In 2014, the value was only 1.69USD per kg of oil, less than half of the inflection point value. At the same time, its growth rate from 2005 to 2014 was slow, only 34.13%. This reflects the problem of slow green manufacturing transformation. Controlling carbon dioxide emissions is a significant starting point for the MTU. In terms of energy consumption, China's energy consumption level is relatively high. Although the GDP per unit energy consumption has increased rapidly at a rate of more than 3 times from 2005 to 2014, it ranks last among the eight major manufacturing countries and is far from reaching the inflection point value.

Overall, the effectiveness of China's MTU has been greatly improved from 2005 to 2014. China's growth rates of indicators all rank among the top 3 of the eight countries. The indicators of manufacturing R & D personnel as a percentage of employees, manufacturing added value, total labor productivity, patent applications, and GDP per unit energy consumption have increased by 2 to 4 times. However, most of the indicator values of China still have a large gap with those of the representative manufacturing countries. According to the growth rate of indicators and the gap between China's indicator values and the inflection point values shown in Figure 4, shortcomings of China's MTU can be divided into three types: (1) The shortcomings of slow green manufacturing transformation and low added value of products, which are reflected by the indicators of D10' and D3', having a large gap with the inflection points but a

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slow catch-up speed. These shortcomings are particularly serious and need to be resolved urgently. (2) The shortcomings of insufficient input of innovation talents, low labor input-output efficiency, and high manufacturing energy consumption, which are revealed by the indicators of D2’, D6’, D8’ and D9’, having a large gap with the inflection points and very fast catch-up speed. (3) The shortcomings of insufficient funding for innovation and inferior industrial structure, which are reflected by the indicators of D1’ and D4’, having a small gap with the inflection points.

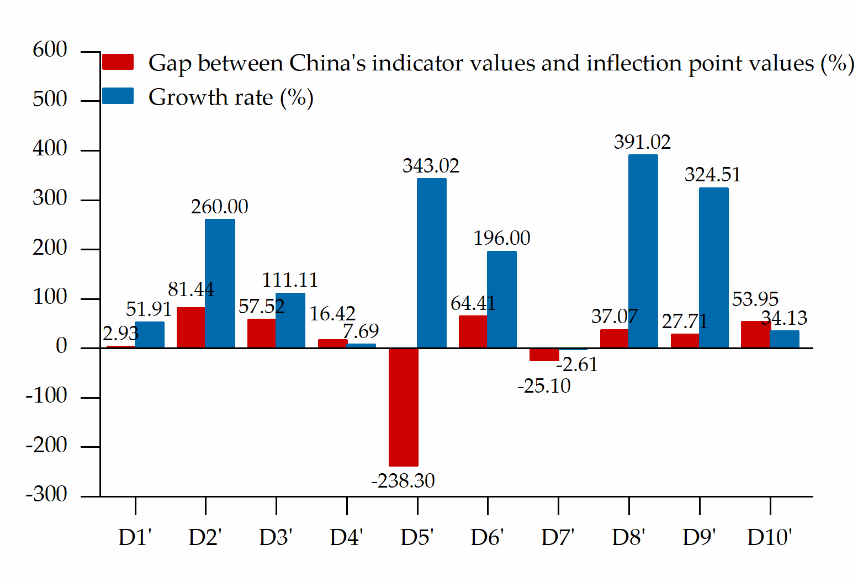

Fig 4: The growth rate of indicators and gap between China’s indicator values and inflection point values

5.3 Provincial Comparison of the Effectiveness of China's Manufacturing Transformation and Upgrading

To identify the regional characteristics of China's MTU, this study further measures the effectiveness of MTU in 31 provinces except Hong Kong, Macao, and Taiwan based on the compound correlation entropy matter element model, evaluation index system of Table 1 and the relevant provincial manufacturing data in 2015. The data was obtained from the China Science and Technology Statistical Yearbook, China Industrial Statistical Yearbook, China Energy Database (by Region), China Environment Database (by Region), and Statistical Yearbook of every province. The results are shown in Table 6.

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TABLE VI. The effectiveness of MTU of 31 provinces of China

province	Power conversion		Structural optimization		Industrial benefit		Ecological benefit		Social contribution		Overall effectiveness	
	Effectiveness	Ranking	Effectiveness	Ranking	Effectiveness	Ranking	Effectiveness	Ranking	Effectiveness	Ranking	Effectiveness	Ranking
Jiangsu	0.7270	2	0.3847	8	0.6614	2	0.7790	1	0.7314	1	0.6555	1
Guangdong	0.7498	1	0.4765	3	0.6778	1	0.7553	2	0.5058	6	0.6486	2
Beijing	0.4399	7	0.7607	1	0.4628	9	0.5850	5	0.5458	3	0.5452	3
Shanghai	0.4938	5	0.3980	5	0.5353	4	0.6624	4	0.5494	2	0.5251	4
Zhejiang	0.4982	4	0.3265	19	0.6350	3	0.5820	6	0.5280	5	0.5234	5
Shandong	0.5211	3	0.3280	18	0.4578	10	0.6860	3	0.5380	4	0.4996	6
Tianjin	0.4525	6	0.4874	2	0.5045	5	0.5234	7	0.4128	8	0.4809	7
Henan	0.3514	15	0.3412	13	0.4665	8	0.4987	11	0.3934	9	0.4134	8
Hunan	0.3745	9	0.3331	15	0.4905	6	0.4346	17	0.3745	23	0.4099	9
Chongqing	0.3515	14	0.3898	7	0.4681	7	0.4220	18	0.3761	20	0.4068	10
Hebei	0.3351	17	0.4182	4	0.4022	18	0.4993	10	0.3695	24	0.4030	11
Fujian	0.3650	12	0.3294	16	0.4171	16	0.5027	9	0.3832	11	0.3999	12

Anhui	0.3694	10	0.3289	17	0.4386	13	0.4647	13	0.3763	19	0.3991	13
Hubei	0.3693	11	0.3228	21	0.4207	15	0.4648	12	0.3886	10	0.3946	14
Liaoning	0.3536	13	0.3205	22	0.4068	17	0.4596	14	0.3773	17	0.3843	15
Jilin	0.3054	28	0.3333	14	0.4523	11	0.4442	16	0.3643	25	0.3839	16
Tibet	0.2917	31	0.3967	6	0.4430	12	0.3334	31	0.4704	7	0.3838	17
Shanxi	0.3298	19	0.3602	10	0.3713	27	0.5028	8	0.3486	30	0.3804	18
Shaanxi	0.3807	8	0.3640	9	0.3824	23	0.3924	22	0.3781	15	0.3799	19
Jiangxi	0.3112	23	0.3519	12	0.3882	21	0.4545	15	0.3757	21	0.3742	20
Guangxi	0.3095	25	0.3029	26	0.4365	14	0.4201	20	0.3566	27	0.3695	21
Sichuan	0.3308	18	0.2903	30	0.4022	19	0.4214	19	0.3826	12	0.3661	22
Hainan	0.3180	20	0.3570	11	0.3921	20	0.3706	26	0.3521	29	0.3596	23
Inner Mongolia	0.3174	21	0.3020	27	0.3742	25	0.4181	21	0.3802	14	0.3566	24
Heilongjiang	0.3411	16	0.3246	20	0.3685	29	0.3679	27	0.3805	13	0.3556	25
Gansu	0.3153	22	0.3137	23	0.3808	24	0.3794	23	0.3479	31	0.3489	26
Xinjiang	0.3009	29	0.2979	29	0.3875	22	0.3644	28	0.3780	16	0.3458	27

Yunnan	0.3069	26	0.3135	24	0.3639	30	0.3761	24	0.3757	22	0.3453	28
Ningxia	0.3112	24	0.3001	28	0.3702	28	0.3538	30	0.3537	28	0.3387	29
Guizhou	0.3066	27	0.2647	31	0.3728	26	0.3623	29	0.3765	18	0.3363	30
Qinghai	0.2996	30	0.3068	25	0.3495	31	0.3721	25	0.3636	26	0.3361	31

According to the effectiveness of MTU, the 31 provinces of China can be divided into five echelons.

The first echelon includes 2 provinces, Jiangsu and Guangdong, whose effectiveness of MTU is far ahead of other regions. Their effectiveness values are 0.6555 and 0.6486 respectively, higher than the overall effectiveness of China with 0.6336 and far higher than that of Beijing ranking third in 31 provinces with 0.5452. From the perspective of the subdivision dimension, the effectiveness of Jiangsu and Guangdong in terms of power conversion, structural optimization, industrial benefit, ecological benefit, and social contribution all ranks among the best in the 31 provinces. That shows that Jiangsu and Guangdong have the most significant effectiveness in promoting power conversion from factor-driven to innovation-driven. Due to the fastest power conversion, these two provinces have realized the optimization of the industrial structure in the manufacturing industry. Their proportions of technology-intensive industries are the highest among the 31 provinces, and their industrial benefit, innovation capacity, ecological benefits, and tax contributions of the manufacturing industries are also much higher than those of other provinces. Jiangsu and Guangdong are the comprehensive leading areas for China's MTU.

The second echelon includes 5 provinces, Beijing, Shanghai, Zhejiang, Shandong, and Tianjin, whose effectiveness of MTU exceed the national average and has obvious advantages in sub-dimensions. Although the effectiveness of provinces in this echelon is slightly lower than the overall effectiveness of China, it is significantly beyond the average of the 31 provinces with 0.4145. The overall effectiveness of Beijing, Shanghai, Zhejiang, Shandong, and Tianjin ranks third to seventh respectively among the 31 provinces. According to the effectiveness of the sub-dimensions, the manufacturing development in these provinces has gradually transformed from the traditional extensive type to the direction relying on technological upgrading and service growth, especially in the provinces of Zhejiang and Shandong. The industrial structure optimization in Beijing and Tianjin is most effective, and the manufacturing

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social contribution in Shanghai is very significant. However, in terms of industrial benefit, ecological benefit, the provinces in this echelon still need to be improved compared to provinces in the first echelons. Besides, some provinces have obvious shortcomings in a certain dimension. For example, the effectiveness of structural optimization in Zhejiang and Shandong is very low. The provinces in this echelon are the partial leading areas for China's MTU.

The third echelon includes 7 provinces, Henan, Hunan, Chongqing, Hebei, Fujian, Anhui, and Hubei, whose effectiveness of MTU is slightly lower than the national average, but has advantages in certain sub-dimensions. The overlap of related strategies makes provinces in this echelon usher in a crucial opportunity period of the MTU. Compared with the average value of the 31 provinces of 0.4145, the overall effectiveness of provinces in this echelon is only 1% lower than that of the whole country. Given the data of sub-dimensions and the regional background, most of the provinces in this echelon are the low-end industrial transfer undertaking areas for the first and second echelons, located in the central part of China. They have an inherently inferior industrial structure compared with Guangdong, Shanghai, Beijing, and other eastern regions. However, through efforts, their traditional labor-intensive, processing-trade, and exogenous development modes of the manufacturing industry have changed to some extent, and the concentration of manufacturing enterprises has increased. Besides, provinces in this echelon are important strategic areas for the development of China's manufacturing industry due to their inherent regional advantages and resource endowments. The successive approval and construction of the "two-oriented society" construction comprehensive supporting reform pilot zone，comprehensive innovation and reform pilot zone, manufacturing innovation center have also provided unique policy opportunities for the provinces in this echelon to transform and upgrade their manufacturing industries, making them the most potential areas to promote China’s MTU.

The fourth echelon includes 8 provinces, Liaoning, Jilin, Tibet, Shanxi, Shaanxi, Jiangxi, Guangxi, and Sichuan, whose effectiveness of MTU is lagging behind in all dimensions. The index data of sub-dimensions and the evaluation values reflect that the industrial structure of provinces in this echelon is single and the manufacturing industry is dominated by the resource-dependent industry. Because of the resource depletion, the extensive development path relying on energy consumption has been locked, and the industrial structure of each province urgently needs to be adjusted. Also, insufficient investment in innovation factors has led to the poor effectiveness of power conversion, low industrial production efficiency, and low innovation benefit. The long-term extensive production mode has caused serious environmental pollution and energy consumption problems, making provinces in that echelon face great pressure for MTU.

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The fifth echelon includes 9 provinces, Hainan, Inner Mongolia, Heilongjiang, Gansu, Xinjiang, Yunnan, Ningxia, Guizhou, and Qinghai, which are the areas with the worst effectiveness in MTU. The index data of sub-dimensions and the evaluation values show that in the provinces of this echelon, the manufacturing scale is small, the economic development is lagging, and the innovation power is lack. Besides, their overall effectiveness and effectiveness in all sub-dimensions are all far lower than other provinces and the gaps between them are extremely obvious. There is a long way to go for their MTU.

VI. CONCLUSIONS AND SUGGESTIONS

6.1 Research Conclusions

According to the connotation of MTU, a five-dimensional evaluation index system, including power conversion, structure optimization, industrial benefit, ecological benefit, and social contribution is constructed. Based on the compound correlation entropy matter element model, the effectiveness of China’s MTU is calculated. By analyzing the effectiveness of China’s MTU from the aspects of development stages, international comparison, and provincial comparison, this study draws the following conclusions.

First, according to the results of development stages analysis, China's MTU has roughly experienced three stages from 2001 to 2015, namely, the inhibition period, the slow development period, and the rapid development period.

Second, the international comparative analysis indicates thatChina's MTU is far from success though its effectiveness has been greatly improved. There is still a large gap of MTU between China and other representative manufacturing countries. Taking 80% of the average of the key evaluation indicators for the world's representative manufacturing countries as inflection point values, which are the criteria for judging whether China’s MTU is successful or not, it is found that except manufacturing value added and profit margin, none of the other indicators in China have met the success criteria for MTU. Compared with representative manufacturing countries, shortcomings of China's MTU can mainly be divided into three types: (1) the shortcomings of slow green manufacturing transformation and low added value of products, which are reflected by the indicators having a large gap with the inflection points but a slow catch-up speed. These shortcomings are particularly serious and need to be resolved urgently. (2) The shortcomings of insufficient input of innovation talents, low labor input-output efficiency, and high manufacturing energy consumption, which are revealed by the indicators having a large gap with the inflection points and very fast catch-up speed. (3) The shortcomings

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of insufficient funding for innovation and inferior industrial structure, which are shown by the indicators having a small gap from the inflection points.

Third, the provincial comparative analysis shows that the 31 provinces of China can be divided into five echelons according to their effectiveness of MTU. The first echelon includes Jiangsu and Guangdong, whose effectiveness of MTU is far ahead of other regions. Provinces in this echelon are the comprehensive leading areas for China's MTU. The second echelon includes Beijing, Shanghai, Zhejiang, Shandong, and Tianjin, whose effectiveness of MTU is above the national average and has obvious advantages in sub-dimensions. Provinces in this echelon are the partial leading areas for China's MTU. The third echelon includes Henan, Hunan, Chongqing, Hebei, Fujian, Anhui, and Hubei, whose effectiveness of MTU is slightly lower than the national average, but has advantages in certain sub-dimensions. The overlap of related strategies makes these provinces usher in a crucial opportunity period for the MTU and makes them the most potential areas to promote China’s MTU. The fourth echelon includes Liaoning, Jilin, Tibet, Shanxi, Shaanxi, Jiangxi, Guangxi, and Sichuan, whose effectiveness of MTU is lagging behind in all dimensions. These provinces are facing great pressure for MTU. The fifth echelon includes 9 provinces, Hainan, Inner Mongolia, Heilongjiang, Gansu, Xinjiang, Yunnan, Ningxia, Guizhou, and Qinghai, which are the areas with the worst effectiveness in MTU. There is a long way to go for their MTU.

6.2 Promotion Suggestions

Based on the above conclusions, two suggestions are made to improve the effectiveness of China’s MTU.

First, choose different strategies for the MTU based on the shortcoming types. For the shortcomings of the first type - slow green manufacturing transformation and low added value of products, it is recommended to adopt the speed-focused strategy, namely, accelerate the supply-side structural reforms and innovation in green technology to realize clean production more quickly and focus on the cultivation of advanced production factors and local leading enterprises exporting high value-added products to speed up the climbing of China’s manufacturing to the high end of the global value chain. For the shortcomings of the second type - insufficient input of innovation talents, low labor input-output efficiency, and high manufacturing energy consumption, it is suggested to use the quality-focused strategy. On the one hand, deepen the introduction and growth mechanism of innovation talents and implementing joint training programs for high-level talents to raise the quantity and quality of talents and improve the input-output efficiency. On the other hand, upgrade the production technologies and equipment to reduce energy consumption. For the shortcomings of the third type - insufficient funding for innovation and inferior industrial structure, it is better to use the

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cross strategy, selecting to focus on speed or quality according to the specific circumstances. For example, set up a special innovative fund pool and appropriately increase R & D investment to ensure sufficient fund for technical innovation, strengthen subsidies to enterprises in high-tech industries, improve the management and operation of high-tech zones and encourage the concentration of high-tech industries to quicken the structural optimization of the manufacturing industry.

Second, develop various strategies for MTU based on regional characteristics. For the provinces in the first echelon, it is suggested to adopt the maintenance strategy, keeping their current leading competitive advantages and building these provinces into demonstration areas to give full play to their radiation driving effect on other areas. For the provinces in the second echelon, it is recommended to use the strategy of making up for the disadvantages. Continue to play the advantages of certain sub-dimensions, and make up for the shortcomings of other week sub-dimensions according to the reality of different provinces. For the provinces in the third echelon, the strategy of tackling key problems should be utilized. These provinces should seize the significant opportunities brought by the overlap of related strategies, and focus on dealing with the retrogression and changes of backward industries and vigorously developing the advanced manufacturing industries. For the provinces in the fourth echelon, the strategy of comprehensive promotion should be introduced. Provinces in this echelon can increase the innovative input, upgrade the production equipment, and strengthen industrial integration to improve industrial benefit and social contribution, build independent intellectual property rights and independent brands to improve their position in the industrial value chain, encourage technological innovation and model innovation to promote power conversion and realize the green transformation of the mode of production. For the provinces in the fifth echelon, the strategy of partial breakthrough is advised, namely, promote the MTU by taking their characteristic leading industries and certain strategic emerging industries as breakthrough points. On the one hand, governments can focus on increasing the scale of the leading industries with regional characteristics to form scale effects. On the other hand, they can also improve the infrastructure conditions and try to build an innovation service system to facilitate the development of certain strategic emerging industries and related enterprises with good innovation capabilities, thus create differentiated competitive advantages and achieve sustainable development.

ACKNOWLEDGMENTS

This study was supported by the Chinese National Funding of Social Sciences (grant no.17BGL209) and the Fundamental Research Funds for the Central Universities (grant no. 2019-JL-005).

AUTHOR CONTRIBUTIONS

Conceptualization, R.M. and Y.H.; methodology, Y.H. and Q.Z.; Data Curation, L.C. and L.Z.; writing-original draft preparation, L.Z. and L.C.; writing- review and editing, L.Z. and R.M.; funding acquisition, R.M.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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