INDUSTRIAL INNOVATION ON THE GREEN TRANSFORMATION OF MANUFACTURING COMMERCE

Tayyab Khan¹, Ayesha Khan²*, Wei Long³*, Tauqeer Khan⁴, Sundas Ayub⁵

ABSTRACT
Manufacturing industry is the foundation and pillar of the national economy. Under the background of China’s economic development entering a new era and fully implementing the innovation driven development strategy, the manufacturing sector’s level of green transformation has realized as one of the key indicators of China’s economic development. Technology innovation-driven green manufacturing industry transformation is a key strategy to achieve high-quality economic development and boost global competitiveness in the context of a new round of technological revolution and industrial reform that are closely entwined with China’s economic transformation and development. Based on this, we take the green transformation of China’s manufacturing industry as the theme, focuses on industries, regions, and strategic industries, and explores the impact and spatial linkage effect of technological innovation on the green transformation of manufacturing industry. Based on the research perspective of manufacturing industry development heterogeneity, we construct the Slack based measure Undesirable-Malmquist-Tobit comprehensive evaluation method and puts forward the driving role and impact of technological innovation on the green transformation of manufacturing industry. The manufacturing industry is categorized into three categories based on the level of pollution, such as clean industry, medium pollution industry and heavy pollution industry. It is found that the green development efficiency of manufacturing clean industry is the highest, followed by heavy pollution industry, and the efficiency of medium pollution industry is the lowest.

Keywords: Technological Innovation; Manufacturing; Green Transformation; Efficiency Measurement.

¹ Wuhan University of Technology, Wuhan, 430070, China.
² Wuhan University of Technology, Wuhan, 430070, China. Email: ayeshakhan@qq.com
³ Wuhan University of Technology, Wuhan, 430070, China. Email: longwei@whut.edu.cn
⁴ Wuhan University of Technology, Wuhan, 430070, China.
⁵ Shandong University, Jinan, China.
*Corresponding Authors
INTRODUCTION

With the prominence of energy and environmental issues, green development has gradually become the growth concept of worldwide. “Made in China 2025” clearly states that the main development direction and important focus of a manufacturing powerhouse is green development. Study (Ralph et al., 2022) pointed out that green manufacturing is the embodiment of sustainable progress in the manufacturing process. It is a modern manufacturing mode under the constraints of environment and energy. Green development, according to the literature (Hsu & Immanuel CY, 1974) emphasizes the combined growth of economic development and environmental conservation. Green development is a new economic concept that emphasizes the interconnectedness of economic growth, social improvement, and environmental construction (Fang et al., 2020).

The green transformation of engineering industry is the transformation from the traditional extensive growth mode to the scientific intensive new development mode on the basis of green development. It is a dynamic system process to improve the total factor productivity of manufacturing industry and realize the intensive and sustainable utilization of energy driven by technological innovation. The essence of economic growth mode is reflected in total factor productivity (Wu et al., 2017; Bruton et al., 2021). Entire factor productivity is the comprehensive embodiment of the improvement of production unit technology and efficiency, as well as the upgrading of management mode and structure. At present, digital technology has widely penetrated into production and life, and the digital economy is booming. Digital industrialization and industrial digitization are accelerating. The deep integration of the digital economy and the real economy has become an important path to promote the green and high-quality development of manufacturing production methods (Kniazieva, 2021). On the one hand, the digital economy can not only effectively improve the production process, improve the efficiency of equipment operation, but also improve the accuracy of production process management. Improve production efficiency and energy saving and emission reduction through intelligent collaborative management (Liu et al., 2021). On the other hand, the digital economy can effectively optimize the pattern of resource allocation. Digital infrastructure in the fields of industrial Internet, big data, artificial intelligence, etc., can realize the integration and sharing of various resource elements of different industries and different enterprises. Resource allocation efficiency helps to be further improved through digital technology (Pan et al., 2022). Digital product innovation is the combination of new products or services that incorporate digital technologies, i.e., information, computing, communication, and
connectivity technologies, or are supported by these digital technologies (Nagaraj, 2022; Jummani et al., 2019). Digital process innovation is the application of digital technology to improve or even reconstruct the original innovation process framework (Soluk, 2022). Digital organizational innovation means that digital technologies change the form or governance structure of an organization (Zhen et al., 2021). Digital business model innovation is to embed digital technology to change the original business model (Palmié et al., 2022). Compared with the development mode in which traditional factors contribute to economic growth, the mode in which total factor productivity promotes economic growth is scientific intensive (Du et al., 2021; Yu et al., 2021).

The development of total factor productivity, instead, is the new driving strength of economic transformation (Zhou et al., 2020). The key factor in industrial transformation is the increase in total factor productivity (Peng et al., 2020). The major goal of industrial transformation and upgrading from the supply side is to increase total factor productivity (Wu et al., 2021). As a result, improving total influence yield in the industrial growth process is critical to achieving the green change of China’s engineering industry. Based on this, this paper takes manufacturing total factor productivity as the basis to measure manufacturing transformation. Figure 1 depicts the internal development mechanism for the manufacturing industry's green transformation in order to endorse the achievement of a new manufacturing industry green development model. We propose the SBM undesirable (Slack Based Measure) model, industry development heterogeneity, build a comprehensive measurement method, and will strive to achieve the following innovative objectives:

i. Based on the perspective of industry development heterogeneity, build a comprehensive measurement method including three stages.

ii. Evaluate green development efficiency Global Malmquist Luenberger (GML) method and whole influence productivity of manufacturing industry.

iii. Based on Porter hypothesis, explore the driving effect and static influence of technological novelty on the green transformation of industrial engineering.
According to a summary of the existing literature, limited studies have considered the high-quality progress of the manufacturing area, with the majority of them intent on the impact of ecofriendly regulation on technological innovation or green revolution in the manufacturing industry (Wang et al., 2014; Wang et al., 2014; Long et al., 2015). Green transition has become one of the most important directions for the further development of the world. It involves the development of green technologies and the formulation of laws and regulations, for example, to save energy or reduce greenhouse gas emissions, as well as any other activity aimed at changing society's attitudes towards acceptance of more expensive but more environmentally friendly technological solutions and legal norms. Therefore, green transition can be defined as the combination of economic growth and care for the environment to ensure a high quality of life for present and future generations at a level attainable by civilized development, as well as the efficient and rational use of resources available resources. Nonetheless, there is no single globally accepted way of making this transition. It happens in many ways and depends on many different factors (Cheba et al., 2022).

Accelerating the intelligent transformation of manufacturing industry is an important strategic choice to realize the transformation of green innovation. Based on the perspective of static efficiency and dynamic productivity (Yang et al., 2022) used dynamic spatial lag model (DSAR), mediation effect model and moderation effect model to analyze the impact of manufacturing intelligence on green innovation performance and its internal mechanism from the theoretical and empirical levels. The results show that on a national scale, manufacturing intelligence has a significant role in promoting green innovation performance; the reason that manufacturing intelligence is conducive to the production of "technology promotion effect" and "cost reduction effect", thereby promoting green technology innovation, thereby
effectively increasing desirable output and significantly reducing bad output; there is obvious regional heterogeneity in the impact of manufacturing intelligence on green innovation performance, the impact of manufacturing intelligence on green innovation performance in the eastern region. The improvement effect is significantly higher than that of the central and western regions. Furthermore, analysis showed that green technology progress, rather than green technology efficiency is the main driver for manufacturing intelligence to improve dynamic green innovation performance. In the current situation, technology has impacted all sectors including materials and manufacturing. Green Manufacturing and Internet of Things are two important applications that are applied in key business areas with positive results. (Naim et al., 2022) conducted a study which showed the role of IoT as an emerging technology in Industrial Transformation and in three areas of Marketing Management explained in five research proposals. Their extended research article showcases the relevance of IoT for optimal growth, development and security efforts at Industrial Transformation and Marketing Management. Their research also described the general impact and benefits of green manufacturing in business process models and product life cycle. Their results show that for Industrial Transformation and Marketing Management, Green Manufacturing and Internet of Things can be well integrated. In addition, the work of Industrial Transformation and Marketing Management became effective and contributed to social benefits through the application of Green Manufacturing and Internet of Things.

According to economic theory, high-quality development is driven by basically different influences than high-speed growth, and the value characteristic of development as a total is given more consideration. People are willing to be on the demand side because they are so highly satisfied with high-quality development, which is the upper supply side of innovation-driven development (Jin, 2018). The high-quality change of the manufacturing trade reflects the overall level of development in the number of manufactured in a region or country. Manufacturing’s fundamental attributes may run afoul of the explicit or tacit needs of society in the change approach. When considering the meaning of high-quality development for the industrial sector, it is based on raising the standard of the supply chain, with technological innovation acting as the main motivator. High-quality change of manufacturing not only helps to rush the transformation of new and old dynamic energy in the engineering industry from a "manufacturing power" to a "Green manufacturing power". The construction of the evaluation index system conducts a multi-dimensional dynamic evaluation of the high-quality growth level of the manufacturing industry, which is conducive to the objective analysis of the high-
quality status quo the advance level of China’s manufacturing industry in various regions. It provides an in-depth breakdown of the deeper details because China’s manufacturing industry is at the lower end of the worldwide value chain.

Furthermore, current characterization of manufacturing development worth is often measured in terms of total factor productivity. However, the productivity of these factors reflects technological development. As a result, there are clear limitations in using total factor productivity to gauge how well manufacturing is developing. This study assesses the effectiveness of the high-tech industry’s green total factor productivity and value chain for technological innovation.

**Connotation Inspiration**

There are many ways to influence the transformation and upgrading of innovation-driven industrial structure. (Abernathy et al., 1978) specifically analyzed the path of innovation-driven industrial upgrading and proposed a famous industrial upgrading model. Wilkins et al. believes that innovation will cause production influences to flow from low-productivity divisions to high-productivity divisions, and the reallocation of resources will eventually lead to changes in the industrial structure (Wilkins and Mira, 2008). Rostow et al. pointed out that technology has strong penetration and substitution, which will lead to the birth of a series of new industries (Rostow et al., 1990). The collection of emerging industries and the combination of new production factors will cause changes in the industrial structure and initiate the transformation and advancement of old-style industries.

Porter et al. pointed out in “National Competitive Advantage” that in order to achieve economic revolution and sustainable progress in the innovation-driven stage, the national competitive advantage will change, that is, from relying on natural resources, labor, and other production factors to relying on independent innovation (Porter, 1990). Gereffi et al. pointed out that industrial upgrading is the revolution of industries from low-end to high-end in the value chain, and innovation is an important support for industrial upgrading and transformation (Gereffi et al., 1999). The new normal state of the economy, we need to seek new driving forces for development, one of which is to take industrial invention as a new driving force.

**Technological Innovation Drivers**

Technological innovation is the direct driving force to endorse the transformation and advancement of the manufacturing industry and complete high-quality development. The driving force for reshaping economic evolution and the weapon to promote industrial transformation is the implementation of large-scale technological innovation and technological
transformation at the national level (Liu et al., 2011). The development process driven by technological innovation includes embedded drive, coordination drive, integration drive and reverse drive (Li et al., 2022). The growing of a country’s economy is primarily determined by the accumulation of endogenous knowledge and the improvement of the level of specialized manpower, both of which come from long-term and stable R&D investment.

Foreign direct investment (FDI) is now a major technological spillover channel (Hering et al., 2014), bringing not just advanced managerial knowledge, but also having a certain impact on the economies and environments of trading countries (Al-Mulali et al., 2013). Technology spillovers refer to the foreign direct investment of multinational corporations in the host country, which leads to the advancement of technology or productivity. Outward Foreign Direct Investment (OFDI) refers to the acquisition or purchase of shares in countries or regions with developed industries or advanced technologies to participate in or direct operations, which can acquire and absorb advanced technologies and help recover the affordability of enterprises. Therefore, the driving factors of technological novelty in this paper mainly come from R&D investment and the development of high-tech industries. FDI and OFDI are included in the evaluation system as technology spillover effects to discover the driving outcome of technological innovation on the green revolution of manufacturing.

**Influence Mechanism**

The change of industrial structure level is reflected in the process of economic development, which is the concrete manifestation of economic transformation and development (Liang et al., 2021). German economist Hoffman et al. (Hoffmann and Walther G, 1958) analyzed the evolution trend of the industrial sector structure in the process of industrialization, and put forward the “Hoffman's Theorem”, that is, the deeper the degree of industrialization, the lower the net asset ratio of the consumer goods industry and the capital goods industry. Author in (Rajan et al., 2001) proposed that priority should be given to the development of advantageous industries with high income elasticity, rapid productivity growth, and high rate of technological progress.

However, the fundamental driving force of economic growth since industrialization is the minor industry, and the contribution of the tertiary commerce to economic growth is subordinate to the secondary industry (Zhou et al., 2021). The development of the industrial construction is not based on the first, second and third industries, but is cyclically fluctuating under the impetus of technological innovation, which is characterized by a wave or spiral
development. Additionally, as it undergoes transformation, the manufacturing sector, reliant on the high-tech sector that employs a lot of technology, pushes the traditional manufacturing sector to continuously realize progressive innovation, improve its capacity for independent and collaborative innovation, and enhance its economic development mode and quality.

**CONCEPTUAL FRAMEWORK**

Based on the breakdown of the connotation and mechanism of green transformation of manufacturing industry, the specific research framework and innovations of this paper are as follows:

1. This article analyzes and reviews the current state of the study in the areas of manufacturing transformation mode, green development and efficiency, and the influence of technical innovation on manufacturing green transformation. Using this as a foundation, the article focuses on technical innovation and green transformation of manufacturing industry from the standpoint of industry, region, and strategic industry.
2. We define the concept of manufacturing green change, analyzes the characteristics of manufacturing green transformation, and expands the connotation of manufacturing transformation.
3. This paper constructs the slack based measure undesirable Malmquist Tobit comprehensive analysis method, and studies the driving effect and static influence of technological revolution on manufacturing industry green change under the background of the intersection of governance transformation and green development concept.
4. Based on the research perspective of efficiency measurement, this paper evaluates the efficiency of high-tech novelty charge chain and green total influence output of high-tech industry by constructing network Slack Based Measure model and Global Malmquist Luenberger index model.

**RESEARCH METHODOLOGY**

*Green Transformation Trend in Manufacturing*

According to the current study (Fan et al., 2021), the green transformation degree of manufacturing industry can be further analyzed by the green entire influence productivity calculated by GML index model. Taking 2008 as the base period, the green total feature output in 2008 is 1. The current situation of green transformation in other years is the product of the GML (Global Malmquist Luenberger) index of that year and the green total factor productivity of the previous year. The calculation formula is as follows:
\[ GT_{2008} = 1 \]  
\[ GT_{it} = 1 \times \prod_{t=2008}^{T} GML_{it} \]

where, \( i \) is the province, \( i = 1, \ldots, 30; t \) is the time, \( t = 2008, \ldots, 2020 \).

Manufacturing total factor productivity can effectively analyze and measure the transformation efficiency between different economic development modes (Bi et al., 2016). Before exploring the influence of technological invention on the green transformation of manufacturing, first discusses the green total factor productivity (GTFP) of manufacturing development trend and green transformation (GT) degree to calculate and analyze. Due to the availability and uniformity of data, uses the facts of 30 provinces and cities in China from 2008 to 2020 (excluding Tibet, Hong Kong, Macao, and Taiwan) for decomposition analysis using Global Malmquist Luenberger, as shown in Figures 2 and 3.

![Figure 2. Green Transformation Efficiency of Manufacturing Industry](image)

![Figure 3. Degree of Green Transformation in Manufacturing](image)
Figures 2 and 3 show the efficiency and extent of green change in the manufacturing commerce. From 2008 to 2020, the trend of green evolution in the manufacturing industry fluctuated slightly, but the overall trend was on the rise. GTFP in 2008-2009 was lower than the production frontier, as well as in 2012-2014 was higher than the production frontier, indicating that environmental governance has achieved certain results. As a result, as environmental regulations improve, manufacturing enterprises continue to increase corresponding production costs in order to reduce pollution emissions, and the manufacturing industry’s development has been hampered. However, while the green transformation process of the manufacturing industry is hampered in the short term, as shown in Figure 3, the degree of green renovation of the manufacturing industry has shown a fluctuation in the long run.

**EKC Curve of Green Manufacturing Development**

The connection among economic development and environmental pollution is often analyzed by the Environment Kuznets Curve (EKC). Therefore, we use energy consumption as an indicator of environmental pollution to explore the affiliation among manufacturing development and environmental pollution in the context of the change of the new economic era. According to the empirical research (Hao et al., 2014), the benchmark as:

\[
\ln e_{it} = \alpha_i + \gamma_t + \beta_1 \ln y_{it} + \beta_2 (\ln y_{it})^2 + \beta_3 (\ln y_{it})^3 + \epsilon_{it}
\]  

(3)

where, \(i\) represents the province, \(t\) represents the year, \(e_{it}\) represents the per capita energy consumption of province \(i\) in period \(t\), \(y_{it}\) represents the per capita GDP of province \(i\) in period \(t\), \(\alpha_i\) represents the provincial cross-sectional effect that does not change with time, \(\gamma_t\) represents the time series effect, \(\epsilon_{it}\) represents the random disturbance term.

As shown in Figure 4, the comprehensive evaluation method mainly consists of three steps: The first step is to classify the manufacturing industry according to the intensity of environmental pollution. The second step is to use the Slack Based Measure (SBM)-undesirable-Malmquist model to evaluate the green development efficiency and total factor productivity of different industries. Finally, based on Porter’s premise, a static panel model is built to empirically investigate the compound driving impacts of environmental legislation and technological innovation on the green transformation of industry.
Due to the availability of data, the green expansion efficiency and entire factor output of 27 manufacturing industries are analyzed in this paper. According to the environmental contamination strength of different industries, this chapter adopts the method proposed in (Li et al., 2012) to split the manufacturing industry into strongly infecting industries, temperately polluting industries, and cleaning industries for research purposes. The following are the specifics: To begin, compute each industry’s pollution emission value as follows:

\[ UE_{ij} = \frac{E_{ij}}{O_i} \]  

where, \( E_{ij} \) represents the main pollutant \( j (j = 1, \ldots, n) \) of the sub-industry \( i (i = 1, \ldots, m) \). Emissions; \( O_i \) represents the total output value of sub-sector \( i (i = 1, \ldots, m) \).

Then, according to the value range \([0-1]\), linearize the pollution emission values of each industry is as:

\[ UE_{ij}^* = \frac{UE_{ij} - \min(UE_j)}{\max(UE_j) - \min(UE_j)} \]  

Based on the research purpose and data availability, the research time and area are 30 provinces in China from 2008 to 2020. This paper selects the per capita manufacturing energy consumption as the environmental pollution index, and the per capita manufacturing main business income represents the manufacturing development index. Variable selection and information sources are shown in table 1.
Table 1. Variable Selection and Data Sources

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symbol</th>
<th>Indicator</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Pollution Index</td>
<td>e</td>
<td>Per capita energy consumption</td>
<td>Tons of standard coal / person</td>
</tr>
<tr>
<td>Manufacturing Development Indicators</td>
<td>GDP</td>
<td>Per capita main business income</td>
<td>Money / person</td>
</tr>
</tbody>
</table>

Note: the info comes from China Energy Statistics, China Statistics, and China Industrial Statistics Yearbooks

RESULTS AND DISCUSSION

Economic Development

The speed of economic growth has slowed in the new era of economic development, and the focus has switched from high-speed to high-quality development. China's economic growth rate has been decreasing since 2010. According to the scale effect of economic development on environmental quality, a slowdown in economic development is beneficial to reducing China's demand for total energy, hence reducing pressure on the ecological environment in some places. All pointers and information sources are shown in Table 2. Relevant data come from “China Foreign Economic and Trade Statistical Year-book” and “China Industrial Statistical Year-book”. The statistics of environment variables are shown in Table 3.

Table 2. Indicator Range and Data Sources

<table>
<thead>
<tr>
<th>Index</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input indicator</td>
<td>Net fixed assets (Billion yuan)</td>
</tr>
<tr>
<td></td>
<td>Number of workers (10,000 people)</td>
</tr>
<tr>
<td></td>
<td>Total Manufacturing Energy Consumption (Mtce)</td>
</tr>
<tr>
<td>Expected output</td>
<td>Manufacturing output value (Billion yuan)</td>
</tr>
<tr>
<td>Undesired output</td>
<td>Carbon dioxide emissions (Mtce)</td>
</tr>
</tbody>
</table>

Table 3. Statistics of Study Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>er</td>
<td>Environmental regulation</td>
<td>%</td>
</tr>
<tr>
<td>rd</td>
<td>R&amp;D spending</td>
<td>$10^4$ Yuan</td>
</tr>
<tr>
<td>fdi</td>
<td>Foreign direct investment</td>
<td>%</td>
</tr>
<tr>
<td>gt</td>
<td>Transformation of government governance</td>
<td>%</td>
</tr>
</tbody>
</table>

The environmental impact factors in the production process, incorporates environmental pollution into the evaluation system, and uses the SBM-undesirable model to estimate the green development proficiency of the manufacturing industry. The green change efficiency of heavily polluted industries is shown in Table 4.
It can be realized from the table that the heavily polluting productions are conquered by energy-intensive industries and traditional industries. Although the green development efficiency of heavily polluting industries varied slightly, it mostly showed an upward trend, with an average efficiency of 0.40 during the study period. The petroleum processing sector, ferrous industry, non-ferrous industry, and chemical industry have green development efficiencies of 0.86, 0.65, 0.50, and 0.40, respectively. These sectors have a higher green development efficiency than other significantly polluting industries. Therefore, it can be found from the results that the green coordinated development capacity of the heavily polluting industries has gradually been improved. Chemical manufacturing, beverage manufacturing, textile, paper goods, and non-metal products have green development efficiencies of 0.26, 0.27, 0.33, and 0.17, respectively. These industries’ green development efficiency is lower than the average efficiency of significantly polluting industries, indicating that their ecological controls are generally inefficient. The industrial added value generally shows a fluctuating growth trend, as shown in Figure 5, the progress rate fluctuates greatly.

![Figure 5. Industrial added value and growth rate in 2008-2019](image-url)
The high-quality change of the manufacturing industry is the key to economic transformation and the essence of the manufacturing industry's green transformation, based on its status and role in the national economy. Manufacturing fixed asset investment has progressively increased and stabilized since 2008, as shown in Figure 6, and the growth rate of manufacturing fixed asset investment from 2014 to 2017 was lower than from 2008 to 2014. The added value of the engineering industry also showed an increasing trend, and the added value of the manufacturing industry was higher than the speculation in fixed assets, indicating that the growth capacity of the manufacturing industry continued to be stable. In 2017, the added value of China’s engineering industry was 3.46 trillion U.S. dollars, and the additional worth of the U.S. manufacturing industry was 2.17 trillion U.S. dollars. The extra cost of China’s manufacturing industry was 1.59 times that of the United States.

![Figure 6. Asset investment and manufacturing value added, 2008-2017](image)

**Industrial Structure Adjustment**

With the economic growth and the optimization and modification of the industrial structure, the output and input structure of economic activities are constantly changing. Moreover, based on the theory of industrial structure, the change of industrial structure level is reflected in the process of economic development, and is the concrete manifestation of economic transformation and development. The total factor productivity (TFP) of the manufacturing industry is analyzed using the Malmquist index model, as well as EC (Efficiency Change) and TC (Technological Change), respectively. As shown in Table 5, from the industry normal, the EC of the cleaning manufacturing is 1.019.
Table 5. Total Factor Productivity of Manufacturing Cleaning Industry

<table>
<thead>
<tr>
<th>Industry</th>
<th>EC</th>
<th>TC</th>
<th>TFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobacco</td>
<td>1.000</td>
<td>1.188</td>
<td>1.188</td>
</tr>
<tr>
<td>Special equipment</td>
<td>1.016</td>
<td>1.074</td>
<td>1.091</td>
</tr>
<tr>
<td>Instrument</td>
<td>1.033</td>
<td>1.012</td>
<td>1.046</td>
</tr>
<tr>
<td>General equipment</td>
<td>1.001</td>
<td>1.081</td>
<td>1.083</td>
</tr>
<tr>
<td>Furniture</td>
<td>1.100</td>
<td>0.972</td>
<td>1.069</td>
</tr>
<tr>
<td>Wood products</td>
<td>1.041</td>
<td>1.076</td>
<td>1.120</td>
</tr>
<tr>
<td>Printing and recording</td>
<td>1.054</td>
<td>1.067</td>
<td>1.124</td>
</tr>
<tr>
<td>Electronic equipment</td>
<td>1.000</td>
<td>1.018</td>
<td>1.018</td>
</tr>
<tr>
<td>Electrical machinery</td>
<td>1.041</td>
<td>1.045</td>
<td>1.087</td>
</tr>
<tr>
<td>Crafts manufacturing</td>
<td>0.900</td>
<td>1.176</td>
<td>1.059</td>
</tr>
</tbody>
</table>

In comparison to the excessively polluted industry, the cleaning industry's resources have been fairly utilized and apportioned. TFP has a mean of 1.089 while TC has a mean of 1.071. The continuous innovation of clean industry technology innovation and the continuous improvement of innovation capabilities will help promote the green transformation of the manufacturing industry. In the early stage of China’s economic development, the development of the industrial structure was unreasonable, and the secondary industry dominated by energy-intensive industries occupied the main position of the economic structure. From the perspective of output, that is, the contribution rate of the three industries to GDP, as shown in Figure 7.

![Figure 7. Contribution rate of three industries to GDP from 2008 to 2018](image-url)
At existing, the dominant industry in China’s economic assembly is the tertiary industry, which indicates that the factors of production have removed from labor- or capital-intensive industries to technology- and knowledge-intensive industries, and China has gradually entered a post-industrial era dominated by service industries (Dasgupta et al., 2002). The continuous optimization of the industrial structure provides a good development environment for the green transformation of manufacturing.

**Technological Innovation and Development**

Research and development (R&D) asset will promote technological improvement, which in turn will have an impact on environmental quality. Innovation is the important driving force of the new era of economic development, and technological novelty is the first driving strength for the high-quality expansion of the manufacturing industry. As shown in Figure 8, R&D spending continues to rise rapidly.

![Figure 8. R&D expenditure in 2008-2019](image)

In 2019, China’s R&D investment strength reached 2.23%, and the total investment reached 2214.316 billion yuan. In addition, the proportion of basic research funding has reached 6.03%, and the overall innovation capability and investment structure have gradually improved. From the view of technological invention output, the number of authorized patents and invention patents in China has shown a rapid upward trend, as shown in Table 6.
Table 6. Number of patents granted, and invention patents granted from 2008 to 2017

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of patents granted (items)</th>
<th>Number of invention patents authorized (items)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>380,000</td>
<td>100,000</td>
</tr>
<tr>
<td>2009</td>
<td>620,000</td>
<td>120,000</td>
</tr>
<tr>
<td>2010</td>
<td>800,000</td>
<td>150,000</td>
</tr>
<tr>
<td>2011</td>
<td>900,000</td>
<td>175,000</td>
</tr>
<tr>
<td>2012</td>
<td>1,250,000</td>
<td>230,000</td>
</tr>
<tr>
<td>2013</td>
<td>1,350,000</td>
<td>210,000</td>
</tr>
<tr>
<td>2014</td>
<td>1,300,000</td>
<td>235,000</td>
</tr>
<tr>
<td>2015</td>
<td>1,650,000</td>
<td>360,000</td>
</tr>
<tr>
<td>2016</td>
<td>1,700,000</td>
<td>400,000</td>
</tr>
<tr>
<td>2017</td>
<td>1,750,000</td>
<td>415,000</td>
</tr>
</tbody>
</table>

According to a study from the Intellectual Property Office, China had placed first in the world for seven years in a row in terms of innovative patent applications. The SBM Undesirable standard is used to examine the manufacturing industry's green progress efficiency, and the green development coordination ability between the manufacturing industry's development and the environment is discussed. According to the findings, the clean manufacturing industry has the highest green development efficiency, followed by the extremely polluted industry and the moderately polluted industry, which has the lowest. Moreover, the overall influence output of the manufacturing industry is on the rise. Based on the observed results, relevant policy recommendations are put forward.

**CONCLUSION**

Technological innovation-driven green revolution of manufacturing industry is a vital means to reach high-quality economic development and improve international competitiveness in the framework of a new round of technological change and industrial reform closely intertwined with China’s economic transformation and expansion. Based on the heterogeneity of the development of manufacturing industries, the static panel model is used based on the panel info of manufacturing industries from 2006 to 2019 to explore the promoting role and static influence of technological invention on the green transformation of manufacturing. The manufacturing industry is categorized into three categories based on its environmental pollution intensity: extremely polluted industries, moderately polluted industries, and clean industries. The SBM-undesirable mode is used to assess the manufacturing industry's green change competence. The clean manufacturing industry has the highest green development efficiency, with a value of 0.52; the extremely polluted industry comes second, with a value of 0.40; and the temperately polluted enterprise has the lowest green development productivity, with a value of 0.32. The significantly polluting industries' mean total factor productivity is
1.106, whereas the EC and TC are 0.944 and 1.145, respectively. The average values of TFP, EC, and TC in the moderately polluted and clean industries are all greater than 1, indicating that resources have been reasonably utilized and allocated in the moderately polluted and clean industries, and the technological innovation capability of the manufacturing industry has been continuously improved. Finally, we employ a static panel model to investigate the combined influence of environmental parameter and technological novelty in driving the green revolution of manufacturing in the context of changing government governance. The results show that R&D asset and government ascendency transformation can directly drive the green transformation of manufacturing.
REFERENCES


Li, L., & Tao, F. (2012). The choice of the optimal environmental regulation intensity in China’s manufacturing industry—Based on the perspective of green total factor productivity. *China Industrial Economics, 5*, 70-82. 10.1088/0022-3727/44/33/335201


Liu, K., & Daly, K. (2011). Foreign direct investment in China manufacturing industry-transformation from a low tech to high tech manufacturing. *International Journal of Business and Management, 6*(7), 15. DOI: 10.5539/IJBM.V6N7P15


This is an open-access article distributed under the Creative Commons Attribution License 4.0.