The Influence of Technological Innovation on High-Quality Development of China's Manufacturing Industry and Its Influence Mechanism

Yuke Wu*, Xinting Chang[a], Jintong Li[b], Wan Wei[c], Yusen Shang[d]

Beijing University of Technology, Beijing China

*wuyuke319@163.com; [a]xinting_rong@163.com; [b]lijintong0904@126.com; [c]1610529420@qq.com; [d]3109524722@qq.com

Abstract. In 2015, the United Nations released its Sustainable Development Agenda, making sustainable development a global trend and the main theme of development among countries. Against this backdrop, the vital role that technological innovation plays in industry upgrading and economic development has been well-recognized. However, how technological innovation influences the manufacturing industry's long-term development remains to be identified, and the specific paths of the influence has not been explored. Therefore, in the present work, an index system to assess the performance of the manufacturing sector in relation to sustainability is put forth. Besides, Furthermore, with panel data of 30 provinces across China over the seven years from 2008 to 2015, the entropy weight method is utilized to determine the level of sustainable development of the manufacturing industry in these provinces. Finally, the impact of technological innovation on the high-quality development of the manufacturing industry is examined. The results revealed that the manufacturing industry in China has substantial regional differences, with Eastern China showing more manufacturing strength than the western provinces; Policy recommendations are proposed for policy-makers to achieve sustainable development of the manufacturing sector, the government can raise investments in technological innovation or advancing the course of urbanization.

Keywords: sustainable development; manufacturing industry; technological innovation

1 INTRODUCTION

Since China started the reform and opening-up initiative in 1978, its manufacturing sector has made remarkable strides and shaped a comprehensive industry system, which significantly contributes to China's economic growth. However, as China ushered in a new phase of economic development by shifting its goal from rapid expansion to quality development, it is imperative to identify what are the contributing factors to high-

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quality development of the manufacturing sector and the underlying mechanism to achieve manufacturing sustainability.

There have thence been extensive studies on high-quality development of the manufacturing industry. Zhang and Qiao [1] established an evaluation system that has seven indexes, that is, the innovation-driven index, structure-optimizing index, speed-efficiency index, factor-efficiency index, quality-branding index, integrated development index, and green development. Shang and Bai [2] revealed the importance of strengthening technological research and development in pushing forward the progress of the manufacturing sector. Yu and Zhang [3] found through empirical analysis that technological innovation can, by rationalizing the structure of the industry and optimizing the industry combination, contribute to transforming and upgrading the manufacturing sector.

As found in this study, the existing systems proposed to measure high-quality development of the manufacturing industry have limitations and await to be improved, and the mechanism underlying the influence of technological innovation on the manufacturing industry's high-quality development remains unclear. These issues are addressed in this study with the 17 sustainable development indicators put forth by the United Nations as a reference benchmark. Specifically, five first-level indicators, namely, social benefit, innovation output, green development, economic development, and structural optimization were selected to construct an assessment system for development of China's manufacturing industry and explore the paths of influences that enable the impact of technological innovation on the manufacturing power.

This paper is comprised of five chapters. Chapter 2 provides an all-round analysis and a review of studies in two streams: studies on high-quality development of the manufacturing sector and research on the interplay between high-quality development of the manufacturing industry and technological innovation. Chapter 3 presents the framework used to measure the level of high-quality development of the manufacturing industry, with panel data from 30 provinces across China. Chapter 4 demonstrates an empirical model used to test how technological innovation affects sustainable advancement of the manufacturing sector and the test outcome. In Chapter 5, conclusions of this study and policy recommendations are provided.

2 LITERATURE REVIEW

Sustainable development has been defined in various ways in previous studies. Li [4] emphasized the need for coordination in sustainable development across three key spheres: nature, society, and economy. Long et al. [5], by exploring the relationship between lean production, internal and external environmental management of enterprises, and sustainability performance of the manufacturing sector, built a hypothetical model for manufacturing sustainability from the dimensions of economy, environment, and society. Long [6] argued that a city's sustainability depends on the combined action of ecological, economic, and social factors under institutional constraints.

As China's economy develops, problems in its manufacturing sector rise as well. The long-term sustainability of the manufacturing sector has gained increasing attention among policy-makers and researchers. Long et al. [5] pointed out the need of transforming the model of development of China's manufacturing industry into a sustainable model characterized by high returns, low energy consumption, and low emissions. Over the years of development, the manufacturing sector is now seeing increased product diversity, accelerated market changes, and enhanced competitive strategies, making it necessary to embrace sustainable technologies to foster sustainable manufacturing [6]. Sustainable manufacturing is designed to minimize the environmental impact of a product or process. Sustainable manufacturing, besides meeting the growing need for "green" products, brings benefits in the operational and financial dimensions, such as reduced use of materials, enhanced design, lower energy consumption and less waste [7].

Meanwhile, there are also extensive reports on the role of technological innovation plays in economic and social development [8] [9]. Some have confirmed the positive role that technological innovation plays in promoting economic advancements across countries [10] [11] [12]. For instance, as reported by Wu et al. [13] and Aali and Venegas [14], technological innovation exerts a significant positive effect on the economic growth in countries and regions including China, Latin America, and Asian countries. Furthermore, Duan et al. [15] stated that technological innovation in China not only stimulates economic development but also allows us to find a balance between economic prosperity and ecological well-being.

Many academics have discovered the notable influence that technological innovation has had on the growth of the manufacturing sector [16]. Qu and Zang [17], using China's provincial-level data, demonstrated that technological innovation is the primary impetus behind China's manufacturing sector to improve the caliber of its exports. According to Mao and Fang [18], technological innovation significantly and directly drives the upgrading and transformation of the manufacturing sector. It also somewhat encourages the expansion of the real economy, which is primarily focused on the manufacturing sector. Sepp and Varblane [16] also confirmed this conclusion based on data from different countries.

Despite the numerous positive effects of technological innovation on manufacturing development, some scholars have found that it may not have a significant positive impact and may even prove detrimental. Feki and Mnif [19], through an analysis of statistics of developing countries from 2004 to 2011, indicated that technological innovation is not conducive to short-term economic prosperity. In Yuan et al.'s [20] work, they found the correlation between the number of patents (representing technological innovation) and the performance of manufacturing high-tech enterprises is not significant. In addition, Liu and Zhang [21], using Chinese data, confirmed that technological innovation does not significantly impact manufacturing exports nor enhance these enterprises' competitiveness in exporting. Moreover, technological innovation has been reported to have a possibility of impairing environmental quality [22-24]. To achieve rapid growth in the economic scale entails improved efficiency in resource utilization and increased investment in natural resources [24].

In summary, the systems to measure the development of the manufacturing sector available so far remain to be improved, and it awaits investigation to identify the role that technological innovation plays in the development of the manufacturing power. Therefore, how technological innovation affects sustainability of the manufacturing sector is examined in the present work.

3 MEASURING THE DEVELOPMENT LEVEL OF CHINA'S MANUFACTURING INDUSTRY

3.1 Measurement framework

In the present work, a measurement system is established to determine the development level of China's manufacturing industry. This constructed system is constructed based on previous knowledge and research findings, encompassing five key dimensions: social benefit, innovation output, green development, economic development, and structural optimization. Additionally, the system has been fine-tuned, considering the notion of high-quality development as well as data availability. Finally, a system consisting of five first-level indicators and 12 second-level indicators is obtained. Specifics of the system and the consisting indexes are presented in Table 1.

Table 1. The development level assessment index system for manufacturing industry

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Measurement
Social benefit	Employment benefits	Job absorption rate	Manufacturing employment/Total regional employment
	Income benefits	Average wage in manufacturing (yuan)	Manufacturing payroll/Manufacturing employment
Innovation output	Patent benefits	Level of patent output for inventions	Number of active patents for inventions in the manufacturing sector/Number of patent applications in the manufacturing sector
		Number of patents for inventions per capital (pieces/10000 people)	Number of active patents for inventions in the manufacturing industry/Average number of employees in the manufacturing industry
	Market benefits	Level of new product output (billion yuan/billion yuan)	Manufacturing new product sales revenue/Industry-wide new product sales revenue

		Technology market turnover per 10000 people active in science and technology	Technology market turnover/Full-time equivalent of manufacturing R&D professionals
Green development	Pollution control	Status of industrial pollution control	The ratio of environmental pollution control investment to regional GDP (%)
			Completed investment in pollution control in the industry (million yuan)
	Pollutant emissions (by pollutant form)	Emissions of industrial pollutants by region	Emissions of industrial solid waste and hazardous waste from major cities (tonnes)
			Emissions of industrial nitrogen oxides and sulphur dioxide (exhaust gases) from major cities (tonnes)
			Industrial production wastewater and sewage discharges in major cities (tonnes)
	Energy utilization rate	Industrial energy utilisation	General industrial combined utilisation rate
Economic development	Pace of development	Growth rate of manufacturing output	(Current year output −previous year's output) / Previous year's output
	Development effectiveness	Profitability of principal business	Manufacturing operational profit/Income of principal business
	Development effectiveness	labour productivity	Industrial value added/Labour force employment
Structural optimization	Industry structure	Advanced manufacturing Structures	High-tech manufacturing output/Gross manufacturing output
		Percentage of high-end manufacturing enterprises	Sum of high-end manufacturing enterprises/Sum of manufacturing enterprises
	Product structure	Percentage of new high-tech products	Sales revenue of high-tech new manufacturing products/Sales revenue of new manufacturing products

3.2 Measurement method and Data sources

Given the statistical features of the selected indicators, the entropy method is employed here to assess the development level of the manufacturing sector in China. Initially, the raw information of statistical data on various evaluation indicators for manufacturing industry development across 30 provinces in China from 2008 to 2015 is processed. This process yields the weight coefficients for each evaluation indicator of high-quality manufacturing industry development. Subsequently, with the indicator system and corresponding weight coefficients, the linear weighting method is utilized to obtain the comprehensive evaluation values of the level of development of the manufacturing industry for each province from 2008 to 2015.

The raw data in this study are from the China Statistical Yearbooks, China Energy Statistical Yearbook, China Labor Statistical Yearbook, China Industrial Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Urban Statistical Yearbook, and provincial statistical yearbooks. Some indicator data in these yearbooks have been changed over time, and the linear interpolation approach is used to make up for the missing data. Notably, some of the indicators are not accessible for manufacturing data. In this case, Su et al.'s [25] approach is applied to use the data for the industry above scale as an approximate substitute. The primary business revenue of the manufacturing sector is utilized in lieu of the manufacturing production value in years when statistical fluctuations in the yearbook indicators cause it to be missing.

3.3 Measurement results and analysis

Analysis of first-level indicators.

Table 2. Weights of first-level indicators

	Social benefit	Innovation output	Green development	Economic development	Structural optimization
weight	0.099	0.432	0.192	0.095	0.182
rank	4	1	2	5	3

Table 2 presents the weights assigned to the five primary first-level indicators. As shown in the table, the indicator "innovation output" marks the largest weight, suggesting the significant role that innovation output plays in transforming and upgrading the manufacturing sector. It is evident that China has given green development more attention in recent years as the green development indicator is second only to the innovation output. The industrial structure indicator weighs in third place, suggesting that the development of medium- and high-end industries should take precedence over the low-end, low-added-value manufacturing sector if the sector is to gradually move up the global value chain. Though the social benefit and economic development indicators rank beneath the other three indicators, they together account for over ten percent of the total weight. In this light, to achieve manufacturing sustainability, we should increase employment, raise laborers' disposable income, and take into account the benefits and quality of economic advances based on three indicators, i.e., innovation output, green development, and optimization of industrial structure.

Analysis of regional heterogeneity

Table 3. Development level and ranking of manufacturing power by province

District / Value/Ranking / A given year		2008		2011		2013		2014		2015	
		Value	Ranking	Value	Ranking	Value	Ranking	Value	Ranking	Value	Ranking
Eastern region	Beijing	0.343	1	0.438	1	0.546	1	0.595	1	0.698	1
	Tianjin	0.222	5	0.238	5	0.286	4	0.297	6	0.332	6
	Hebei	0.122	18	0.114	26	0.129	25	0.158	22	0.183	25
	Liaoning	0.183	8	0.156	11	0.160	16	0.188	18	0.184	24
	Shanghai	0.288	2	0.279	3	0.287	3	0.330	3	0.373	3
	Jiangsu	0.269	3	0.276	4	0.284	5	0.310	5	0.317	7
	Zhejiang	0.136	15	0.145	16	0.170	12	0.200	14	0.303	8
	Fujian	0.154	11	0.181	8	0.198	7	0.213	10	0.219	17
	Shandong	0.158	9	0.174	9	0.194	8	0.318	4	0.371	4
	Guangdong	0.263	4	0.318	2	0.338	2	0.358	2	0.396	2
	Hainan	0.107	25	0.130	18	0.153	20	0.197	16	0.226	14
Central region	Shanxi	0.108	24	0.116	24	0.128	26	0.154	25	0.121	30
	Inner Mongolia	0.096	29	0.112	27	0.127	27	0.150	27	0.152	28
	Jilin	0.102	26	0.118	23	0.159	17	0.151	26	0.207	20
	Heilongjiang	0.141	13	0.103	28	0.122	28	0.144	28	0.210	18
	Anhui	0.112	22	0.125	20	0.159	18	0.219	9	0.204	21
	Jiangxi	0.127	16	0.149	14	0.160	15	0.179	21	0.181	26
	Henan	0.113	21	0.119	22	0.170	13	0.202	12	0.208	19
	Hubei	0.136	14	0.154	13	0.174	11	0.203	11	0.231	13
	Hunan	0.118	20	0.156	10	0.177	10	0.201	13	0.221	16
Western region	Guangxi	0.073	30	0.093	30	0.113	29	0.125	30	0.138	29
	Chongqing	0.102	27	0.155	12	0.152	21	0.188	17	0.199	22
	Sichuan	0.142	12	0.182	7	0.187	9	0.236	8	0.224	15
	Guizhou	0.156	10	0.125	21	0.151	22	0.182	20	0.284	11
	Yunnan	0.096	28	0.116	25	0.148	23	0.157	23	0.286	10

	Shanxi	0.196	7	0.222	6	0.247	6	0.283	7	0.300	9
	Gansu	0.109	23	0.129	19	0.155	19	0.156	24	0.168	27
	Qinghai	0.207	6	0.146	15	0.168	14	0.199	15	0.344	5
	Ningxia	0.120	19	0.100	29	0.101	30	0.133	29	0.233	12
	Xinjiang	0.126	17	0.139	17	0.147	24	0.184	19	0.191	23

As Table 3 shows, 30 provinces are selected as the samples, where 11 are in eastern China, 9 in central China, and 11 in the western part of the country. As the table shows, Beijing, Guangdong, Shanghai, Jiangsu, and Tianjin rank in the top five in terms of their manufacturing strength. These provinces quickly rose to the national manufacturing high-quality development of the "vanguard" due to their strong manufacturing foundation, rapid development speed, geographic advantages, economic benefits, and a number of national policy supports. In addition, Shandong depends on talent, location, economy, and other factors that contribute to the long-term prosperity of the nation's manufacturing sector.

Among the top ten provinces and cities in 2015, three are in the western region and seven in eastern China. And amidst the last ten provinces and cities, two belong to eastern China, four are in central China, and the rest four are in the west. It is evident that China's eastern area has developed manufacturing at a far higher level than the country's central and western regions.

4 EMPIRICAL ANALYSIS

4.1 Modeling

To examine the impact of technological innovation on sustainability of the manufacturing industry, this study builds a regression model.

$$lnqual_{it} = \beta_0 + \beta_1 lntecp_{it} + \beta_2 lnX_{it} + \varepsilon_{it} \tag{1}$$

Logarithmic treatment is applied to all variables to minimize heteroskedasticity in the data. Among them, the letters i, t, and $qual_{it}$ stand for the province, year, and the level of the manufacturing industry's development in Year t of Region i. Moreover, $tecp_{it}$ corresponds to the level of technological innovation in Year t of Region i, X_{it} represents the other five control variables with impacts on the regression results, and ε_{it} denotes the random error term.

4.2 Selection of Variables and Data Sources

- Explanatory variable

In the present work, technological innovation (tecp) serves as the explanatory variable. Per Zheng et al.'s [26] research result, the measure of R&D intensity, which is derived from the ratio of the manufacturing R&D expenses to the GDP, is used in this paper. The data about technological innovation are from statistical yearbooks, such as

China Statistical Yearbook, China Industrial Statistical Yearbook, and Urban Statistical Yearbook.

- Control Variables

The control variables in this study are the factors other than explanatory variables that could affect the manufacturing industry's ability to generate high-quality products. Table 4 presents the control variables that are input to the regression model to preclude biases. Table 4 displays the meanings and data sources:

Table 4. Definitions and data sources of control variables

Control variable abbreviation	Definition	Data sources
urban	Urbanization level	China Population and Employment Statistical Yearbook
gover	Intensity of government expenditure	Local government fiscal expenditure data from China Fiscal Yearbook
fdi	Foreign direct investment	Provincial statistical yearbook
finan	Level of financial development	Provincial statistical yearbook
open	Degree of opening up	Data from China Statistical Yearbook
market	Marketization level	Use marketization index instead, data from China Marketization Index Database

4.3 Analysis of empirical results

- Multicollinearity test

Table 5. Multicollinearity test result

Variable	VIF	1/VIF
market	6.78	0.147417
gover	4.81	0.207708
finan	4.15	0.241167
urban	4.06	0.246103
open	4.02	0.248590
fdi	2.98	0.336030
tecp	1.08	0.926321
Mean VIF	3.98	

The multiple covariance test is performed using Stata18.0 to mitigate the bias triggered by high correlations between the variables. Table 5 shows the results of the multicollinearity tests.

- F-test

The F-test is run on the data to confirm the type of the model being used. As revealed in the results, the P-value is significantly 0, which means that the original hypothesis must be rejected along with the use of the mixed regression model. This suggests that there is an individual effect, and the individual effect model should be selected.

- Hausman test

When the model and regression equation are subjected to the Hausman test, the result is equal to 0.0003, which is less than 0.05. This means the regression should adopt the fixed-effect model and the original hypothesis is rejected. In other words, it is confirmed that the fixed-effect model is a better fit.

- Regression to baseline

As shown in Table 6, the estimated coefficient of technological innovation is positive, which is significant at the 5 percent level, suggesting the effective and supportive part that technological innovation plays in advancing manufacturing sustainability. One possible reason is that the manufacturing industry's general development pattern has been able to change into a high-value-added, technology-intensive industry by adopting cutting-edge technologies and equipment.

The level of marketization is found to have a significant positive impact (at the 1% level) on the control variables. This finding allows us to see that the manufacturing industry should keep expanding the scope of the factor market allocation, push the factor market forward, and further reform the factor market allocation. The improved marketization of commodities and factors of production contributes to higher quality of the manufacturing sector, and the manufacturing sustainability has positive correlation with the level of urbanization at the 1% level, suggesting that enlarging the size of cities or urban areas can be one way to improve the quality of development of the regional manufacturing industry. To boost the growth of the manufacturing sector and enhance people’s living standards, China should continue to encourage urbanization and raise the bar for infrastructure construction across the country. Factors including the financial development degree, foreign direct investment, and openness are all observed to have a positive impact on the industry’s development quality in a non-significant way, suggesting that these factors are improving at the same time.

Table 6. Test results on the impact of technological innovation

	(1)
VARIABLES	ln_qual
ln_tecp	0.0897**
	(0.0436)
ln_finan	0.228
	(0.152)
ln_urban	1.701***

	(0.302)
ln_market	0.602***
	(0.151)
ln_open	0.0790
	(0.0582)
ln_fdi	0.00568
	(0.0366)
ln_gover	-0.0842
	(0.172)
Constant	-9.522***
	(1.276)
Observations	240
Number of region	30
R-squared	0.612

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.4 Robustness test

The influence of potential outliers in the explanatory variables cannot be eliminated by the fixed-effects model. Quantile regression is employed to provide a more thorough and comprehensive interpretation to how technological innovation affects the manufacturing sector's sustainability, and the regression test results are shown in Table 7. As the regression coefficient increases from 0.16 to 0.23, the results demonstrate considerably different beneficial impacts of technological innovation in various inequality distributions and exhibits an increasing trend between different quartiles. All things considered, the quantile regression results support the findings of the benchmark regression and demonstrate that technical innovation can successfully foster the manufacturing sustainability.

Table 7. Results of quartile regression tests on the impact of technological innovation

Variables	Quantile of 0.25	Quantile of 0.5	Quantile of 0.75
Lntecp	0.1608**	0.2005***	0.2304***
	(0.0732)	(0.0570)	(0.0687)
Cons	-3.35***	-2.61***	-3.34***
	(0.8248)	(0.6426)	(0.7738)
Control variables	Yes	Yes	Yes
Obs	240	240	240
Pseudo R^2	0.3190	0.3767	0.4380

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5 RESEARCH CONCLUSIONS AND POLICY-MAKING RECOMMENDATIONS

On the premise of conceptual understanding, an assessment system for the manufacturing industry's high-quality development is established in the present work. Additionally, with panel data of 30 provinces and cities in China from 2008 to 2015, the entropy weight approach is employed to assess the development of the manufacturing sector in China. Meanwhile, the impact of technological innovation is empirically explored using the fixed-effects model. Two conclusions have been reached:

First, an index system intended to measure the level of high-quality development of the manufacturing sector is constructed, consisting of five dimensions. Of these, the contribution of innovation output is the highest, making up 43.2% of the total weight. This means that innovation output can more effectively encourage quality improvement. The remaining characteristics are weighted as follows: green development, industrial structure, social effect, and economic development. From the temporal perspective, China's manufacturing industry has moved up to a consistently higher level from 2008 to 2015. From the spatial perspective, the manufacturing industry in eastern China has witnessed a higher level on average than that central and western China. The manufacturing sector has seen steady, albeit slower, development in central and western China.

Second, the technological innovation is found to have a positive impact on sustainability of the overall manufacturing sector, suggesting that technological innovation can improve manufacturing sustainability throughout China. Among the control variables, urbanization is a key factor in manufacturing sustainability, indicating that urban expansion enhances the regional degree of manufacturing development. Furthermore, the beneficial impact of marketization on manufacturing sustainability is noteworthy, suggesting that marketization contributes positively to manufacturing sustainability.

The research findings have practical relevance and can provide references for policymakers. First and foremost, the government needs to encourage enterprises in the manufacturing industry to engage in technological innovation, which is the cornerstone of manufacturing upgrading. Talents are essential for the industrial sector to flourish at a high standard, and talents at all levels and echelons are needed for innovation. One way the government may encourage independent innovation in business is by providing more R&D subsidies to businesses, which will reduce their R&D cost. Additionally, it is advisable that the government invests more into scientific research and bolster China's capacity for autonomous innovation. By encouraging manufacturing companies to innovate technologically, raise China's level of technological innovation, and realize the leap from a manufacturing power to a manufacturing power.

Secondly, the urbanization trend in the western region needs to be actively supported by the government. As a result of several variables such as location, development level, and other factors, China's manufacturing industry has always developed with clear regional disparities, typically exhibiting a pattern where the eastern region marks a strong manufacturing sector while the west is weaker. Due to resource limitations, the western part of China has a lower level of urbanization. The empirical findings demonstrate that urbanization is a significant factor in the superior growth of the manufacturing sector, which depends on contemporary infrastructure for production, sales, and other aspects. By boosting financial expenditures, the government can actively encourage the urbanization process in the western region by increasing financial expenditures. The infrastructure in the western region should be improved to enhance the living standards. Simultaneously, it enhances the current status quo of uneven levels of manufacturing sustainability in provinces across China and fosters the manufacturing strength of western China.

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