Measurement and Spatiotemporal Evolution Analysis of New Quality Productive Forces in China's Manufacturing Using TOE Theory

Pan Liu, Dong Li, Weilin Nie

Abstract—**The world today is facing a complex situation of geopolitical tensions and intensified competition among major powers, which has led to a wave of "re-industrialization" in the world, making manufacturing the focus of the game between major powers. Disruptive innovation-driven new quality productive forces (NQPF) could accelerate manufacturing to high-quality development and transformation, and upgrading. We use Technology-Organization-Environment (TOE) theory to analyze the theoretical implications of NQPF in manufacturing, construct an evaluation index system covering three levels, and further refine it into four dimensions: new quality labor (NQL), new quality labor material (NQLM), new quality labor object (NQLO), and new quality development environment (NQDE). This study takes 31 provinces in China from 2013 to 2022 as the research object to analyze the development level and spatiotemporal evolution of NQPF in manufacturing. The research found that: (1) The overall level of NQPF in manufacturing was on an upward trend, and the regional development level showed a gradient development pattern of "eastern region leading, central region following, northeastern region trailing, and western region lagging". (2) The development of the TOE level was unbalanced, with the organizational level developing the best, the environment following, and the technical level lagging. The NQLO dimension was the most prominent, and the NQLM dimension was the lowest. (3) The level differences among the four major regions have constantly expanded, and the imbalance between regions has become the main factor restricting overall development, and polarization has occurred in each region. (4) The development of a province had a significant spatial spillover effect on the development of adjacent provinces.**

Index Terms—**new quality productive forces, manufacturing, TOE theory, regional disparities**

Manuscript received April 11, 2025; revised June 28, 2025.

This work was supported in part by the Humanities and Social Sciences Planning Fund Project of the Ministry of Education of China under Grant 24YJA790034, China Postdoctoral Science Foundation General Project under Grant 2022M721039, Henan Province High-level Talent International Training Project under Grant GCC2025016, Henan Province Philosophy and Social Sciences Planning Annual Project under Grant 2024CJJ065, Henan Agricultural University Social Sciences Prosperity Project Key Project under Grant NO.FRZS2024A02, Henan Province Key R&D and Promotion Project (Soft. Science) under Grant 252400411188, Henan Province Young Talent Support Program under Grant 2025HYTP022.

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I. INTRODUCTION

CHINA'S manufacturing is huge in scale, but faces the transformation pain point of being "big but not strong", which restricts its high-quality development. In September 2023, Chinese President Xi Jinping first mentioned NQPF in Heilongjiang province. He emphasized that NQPF is "an advanced productivity form that takes innovation as the core driving force, abandons the old growth model, demonstrates high-tech, high-efficiency, and high-quality characteristics, and conforms to the new development concept". In China, the NQPF, catalyzed by disruptive technological innovation, was elevated to a national strategy in 2024. At the Third Plenary Session of the 20th CPC Central Committee in 2024, he further pointed out that the development of NQPF needs to be adapted according to local conditions. For manufacturing, developing NQPF is not only an urgent need to accelerate the transformation of traditional manufacturing to high-end, but also the key to building a strategic cornerstone for a manufacturing power. Therefore, it is of great significance to study implications, development level, regional disparities, and spatiotemporal evolution of NQPF in manufacturing.

Currently, research about the measurement of NQPF level in manufacturing is limited, and related studies mostly focus on the impacts of NQPF in manufacturing and the path of its formation. For example, Liu and He [1] analyzed the impacts of the synergistic agglomeration mechanism in manufacturing and the modern service industry on the high-quality development in manufacturing. Zhang et al. [2] studied the degree of coupled coordinated development between the NQPF and the carbon emission efficiency of China's inter-provincial manufacturing. Wu and Chen [3] put forward four logics for the NQPF formation of intelligent manufacturing, namely, technological innovation-driven, production model transformation, integration of production factors, and collaborative symbiotic development. Yang et al. [4] discussed how NQPF could enhance the resilience of the manufacturing chain and conducted an index system from three dimensions, namely, risk resistance, supply and demand matching, and energy level leap. Li et al. [5] explored the conditional factors for the formation of NQPF in manufacturing enterprises from the group perspective. In terms of level measurement, Ren et al. [6] measured the development level of NQPF in manufacturing from the multi-dimensional aspects of industrial intelligence, greening, innovation, humanism, safety, and environment. Based on Marx's productivity theory, Zhu et al. [7] measured the development level of NQPF in digital manufacturing from three dimensions, namely, NQL, NQLM, and NQLO.

In other aspects, the measurement research of NQPF has accumulated a certain foundation, which provides strong support for our study. In terms of indicator construction, early studies mostly constructed an indicator system based on the implications of NQPF and Marx's productivity theory, to refine it from three levels, namely, labor, labor object, and labor material [8-11]. With a deeper understanding, scholars recognized that the development of NQPF was driven by multiple factors such as science and technology, green, digital, resource environment, and so on [12-15]. Therefore, scholars have combined the connotation of NQPF and constructed a corresponding indicator system from the multi-dimensions [16-21]. Ma [22] and Yue et al. [23] investigated the function of NQPF in facilitating green development and environmental innovation in enterprises. From the perspective of system theory, NQPF was a complex system intertwined with "technology-factors-industry" [24], and its development was affected by the external environment, such as social system changes [25]. TOE theory has shown significant advantages in analyzing such complex systems [26,27], and by integrating the three dimensions of technology, organization, and environment, it has provided a comprehensive, adaptive, and timely evaluation of the NQPF. The system could not only effectively assess the overall situation of NQPF and avoid one-sidedness, but also highlight the core role of technological innovation, and closely match the national policy guidance and industry development dynamics to ensure the accuracy of the evaluation results.

The existing research has the following deficiencies: (1) The construction of the evaluation index system for the development level of NQPF in China's manufacturing is still insufficient. (2) A few studies conducting in-depth research use TOE theory. (3) There is insufficient attention paid to the development environment of NQPF (including social and policy environment).

Therefore, we first combine TOE theory and Marx's productivity theory to analyze the connotation of NQPF in manufacturing. Then we innovatively construct an evaluation index system for NQPF in manufacturing. Through this system, we could scientifically measure the development level, regional differences, and dynamic change characteristics of NQPF in manufacturing, to provide theoretical support for the formulation of development policies for NQPF in manufacturing.

II. Research Design

A. *Theoretical Implications*

We use TOE theory and combine the characteristics of four dimensions: NQL, NQLM, NQLO, and NQDE, and provide a comprehensive interpretation and discussion on the theoretical connotation of NQPF in manufacturing.

At the technological level. The leap of NQPF is rooted in the construction of digital infrastructure and the accumulation of intangible knowledge capital. High-level R&D investment is the key to promoting this process, especially breakthroughs in cutting-edge technologies such as digitalization and artificial intelligence, which have laid a solid foundation for the transformation and upgrading in manufacturing. More importantly, the R&D and application of green technologies not only lead the industry to move towards a more environmentally friendly and efficient direction, but also become the core engine for shaping the NQPF in manufacturing, which has a far-reaching impact on achieving sustainable development goals.

At the organizational level. The cultivation of NQL and organizational innovation has become the core driving force. The transformation and upgrading of manufacturing rely on new talents with advanced cognitive and practical abilities, who could effectively integrate organizational resources, accelerate the transformation of innovative achievements, and promote industrial upgrading. At the same time, the organizational environment and industrial structure of the NQLO could further promote the release of NQPF by optimizing the coordination mechanism.

At the environmental level. A comprehensive supportive environment is a necessary condition for the vigorous development of NQPF in manufacturing, which includes policy support, market demand guidance, and deepening of opening up. High-level international cooperation and exchanges have introduced global innovation resources to manufacturing. The precise investment of government special funds has provided strong guarantees for technological research and development. The strong growth of market demand has provided broad space for the application of NQPF. These three factors promote each other, focus on the creation of NQDE, and jointly construct a powerful driving force system for the continuous leap of NQPF in manufacturing.

B. *Indicator System Construction*

Through the discussion and understanding of NQPF in manufacturing in the previous section, this study constructed four dimensions: NQL, NQLM, NQLO, and NQDE from the three levels of technology, organization, and environment, and further divided them into 7 primary indicators and 13 secondary indicators for the NQPF comprehensive evaluation index system (The specific quantification methods are shown in Table I).

Technology level. The digitalization level constructed indicators from two aspects: digital infrastructure and digital technology application, referring to the research of Zhang et al. [28], Zhu and Zeng [29]. The technological innovation capacity started from the input and output perspectives, referring to the studies of Ren et al. [6], Lu and Shi [30], Lin and Qiao [31]. Green development level referred to the approach of Wang et al. [32], selecting indicators from two aspects: pollution emission and pollution control.

Organizational level. New quality human resources referred to the research results of Wu and Wan [19], selecting indicators from two aspects: training environment and quality structure. The development level of new quality industries constructed indicators from two aspects: the collaborative environment of the organization and the industrial structure, referring to the research of Dong [9], Liu et al. [33] and Wang [34].

Environment level. The degree of opening up referred to the approach of Zhou et al. [35]. The development of government fiscal supply and market demand referred to

Wang's idea[32].

C. Data Source

According to the standards of the National Bureau of Statistics, we divide China's 31 provinces into four major regions: East, Central, West, and Northeast. The eastern region includes 10 provinces, namely Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central region includes 6 provinces, namely Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region includes 12 provinces, namely Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The northeastern region includes 3 provinces, namely Liaoning, Jilin, and Heilongjiang.

The research data comes from the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Torch Statistical Yearbook, China Environmental Statistical Yearbook, China Tertiary Industry Statistical Yearbook, and China Education Statistical Yearbook from 2014 to 2023. Some missing data are supplemented by the average growth rate and interpolation.

III. Empirical Analysis

Before launching the analysis, we first use a technical roadmap to clarify the research framework and methods to ensure the systematic and scientific nature of the research, as shown in Fig. 1. The subsequent research content is divided into three main parts. First, the Entropy-TOPSIS method [36] is used to evaluate the development level of manufacturing NOPF in various regions, levels and dimensions. Second, by calculating the overall Gini coefficient, the within-group Gini coefficient, and the between-group Gini coefficient, the differences between regions are deeply analyzed. Finally, the spatiotemporal evolution characteristics of the development level of manufacturing NOPF are explored, and the kernel density estimation method and the spatial Markov chain model are used to reveal the characteristics of its temporal evolution and spatial evolution.

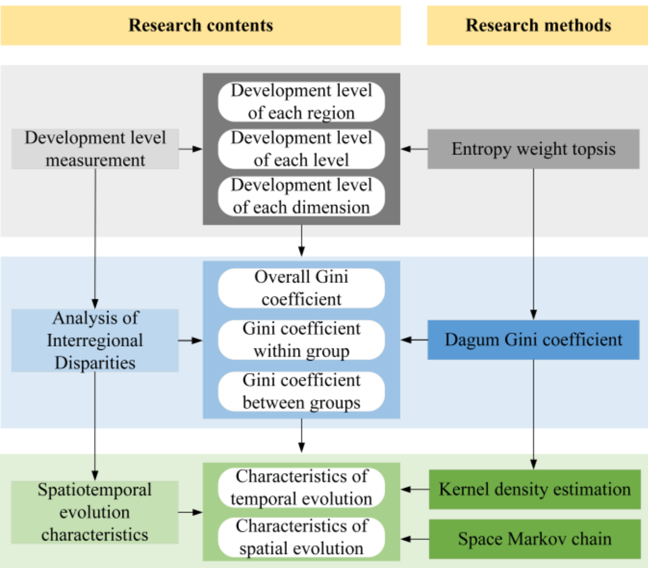

Fig. 1 Technical roadmap.

A. Measurement of Development Level

1) Development Level of Each Region

We use the Entropy-TOPSIS method to measure the level of NQPF in manufacturing in 31 provinces. The results are shown in Table II. From 2013 to 2022, China's manufacturing NQPF generally showed an upward trend, but declined slightly in 2014, 2016, and 2020. The development levels of various provinces vary significantly, with Guangdong (0.479), Jiangsu (0.405), and Beijing (0.341) ranking in the top three. These regions are also in a leading position in terms of scientific and technological innovation capabilities, talent reserves, and degree of openness to the outside world, highlighting the positive impact of economic development levels on improving NQPF in manufacturing. In contrast, Qinghai (0.050), Inner Mongolia (0.049), and Hainan (0.048) ranked lower. This is probably related to their distinctive industrial characteristics (such as animal husbandry in Qinghai and Inner Mongolia, and tourism in Hainan). The economic structure dominated by these characteristic industries has different development paths and driving forces of NQPF in manufacturing, resulting in a relatively low level of NQPF in manufacturing.

As shown in Fig. 2, the average value in the eastern region is ahead of the national average value, while the average value in the central, northeast and western regions is lower than the national average value, showing a gradient development pattern of eastern (0.2447)> central (0.1165)> northeast (0.0885)> western (0.0765). This further confirms that the level of NQPF in manufacturing in regions with advantages in economic development and scientific and technological innovation is generally high, while that in western and northeast regions with relatively weak economic bases is relatively low.

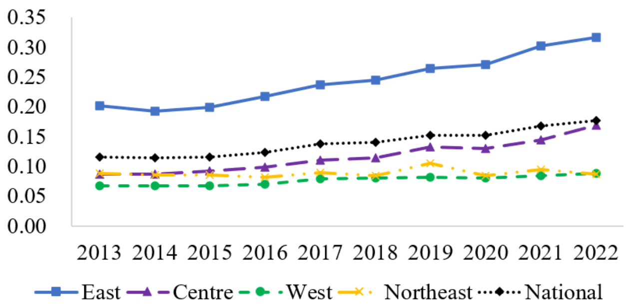

Fig. 2 The development level of NQPF in the four regions.

2) Development Level of Each Level

Technical level (Fig. 3). The level of development of NQPF in manufacturing is increasing year by year. Guangdong (0.510), Jiangsu (0.391), and Zhejiang (0.287) lead the country. The three provinces are all located in economically developed coastal areas, and their manufacturing industries are in the leading position in the country in terms of digitalization, innovation capabilities, and green development. In contrast, Ningxia (0.038), Gansu (0.038), Qinghai (0.036), and Tibet (0.032) all scored below 0.040. They are located in the northwest region, with relatively weak economic foundations and weak overall manufacturing technology levels.

Organizational level (Fig. 4). The level of NQPF in manufacturing also shows a continuous upward trend, from

0.168 in 2013 to 0.231 in 2022. Jiangsu (0.520), Beijing (0.451), and Guangdong (0.436) ranked in the top three, showing significant advantages in talent and industrial agglomeration. Xinjiang (0.100), Hainan (0.087), and Inner Mongolia (0.078) ranked low, and there is a gap between them and the developed provinces in the east and central regions in terms of talent training, industrial collaborative environment, and structural optimization. Although Inner Mongolia is rich in natural resources, its industrial transformation and upgrading process is relatively late.

Environmental level (Fig. 5). The development level of NQPF in manufacturing shows a trend of first falling and then rising, and in 2019, it exceeded the level of 2013. Beijing (0.483), Shanghai (0.438), and Guangdong (0.422) rank at the forefront of the country, with leading economic and industrial layouts, a high degree of openness to the outside world, and strong government support. Hubei is the only province that ranks among the top ten and achieves steady growth year by year, becoming the leader in the central region. The bottom three provinces of Shanxi (0.024), Tibet (0.021), and Xinjiang (0.020) are all located in inland areas. As a major energy province, Shanxi urgently needs to accelerate the transformation of traditional industries, cultivate and expand advanced manufacturing clusters, and promote the development of manufacturing towards high-end, intelligent, and green directions.

Differentiation at the regional technical level (Fig. 6). The development level of NQPF in manufacturing in the central, western, and northeastern regions lags significantly behind that in the eastern region at the technical level, highlighting the significant regional differentiation at this level. Specifically, the development level in the eastern region continues to improve steadily. The central region experienced a slight decline in 2020. The northeastern region experiences large fluctuations. The western region grows the slowest, and its development is constrained by a relatively weak economic foundation and a lack of talent resources.

Regional pattern at the organizational level (Fig. 7). The development trend of NQPF in manufacturing in the four major regions at the organizational level is generally positive, and all have achieved year-on-year improvement. However, the regional pattern remains stable: the eastern region (0.286) > the central region (0.197) > the northeastern region (0.153) > the western region (0.130). Among them, the eastern and central regions have maintained an annual increase, both exceeding the national average (0.195), and the gap between the two has gradually narrowed. In contrast, the western and northeastern regions have limited growth, and their development gap with the eastern and central regions has widened in recent years.

Regional dynamics at the environmental level (Fig. 8). At the environmental level, the development level of NQPF in manufacturing in the eastern region has experienced a decline, especially showing a negative growth trend between 2014 and 2018. The central region has achieved slow but sustained growth, climbing from 0.050 in 2013 to 0.180 in 2022. The development of the western region is relatively stable, with little fluctuation over the past decade. The development path of the northeastern region is relatively tortuous. After a decline, it rebounded briefly in 2019, but then fell again.

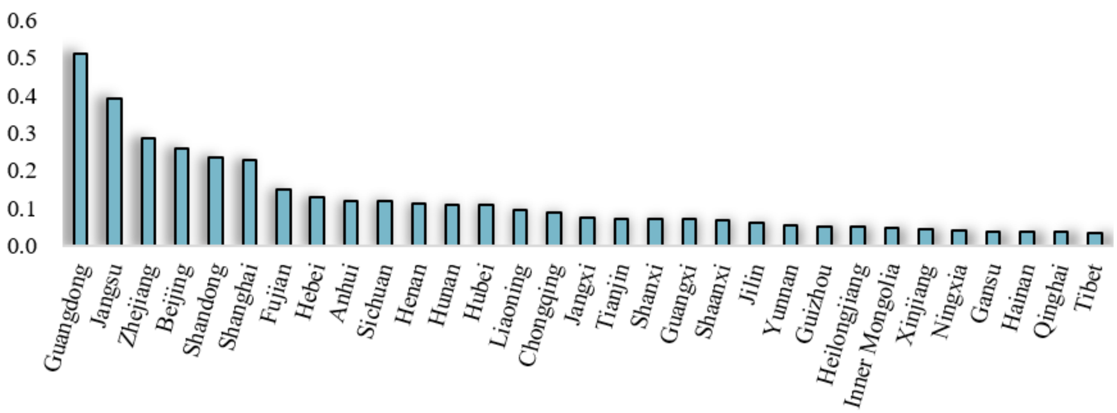

Fig. 3 Technical level.

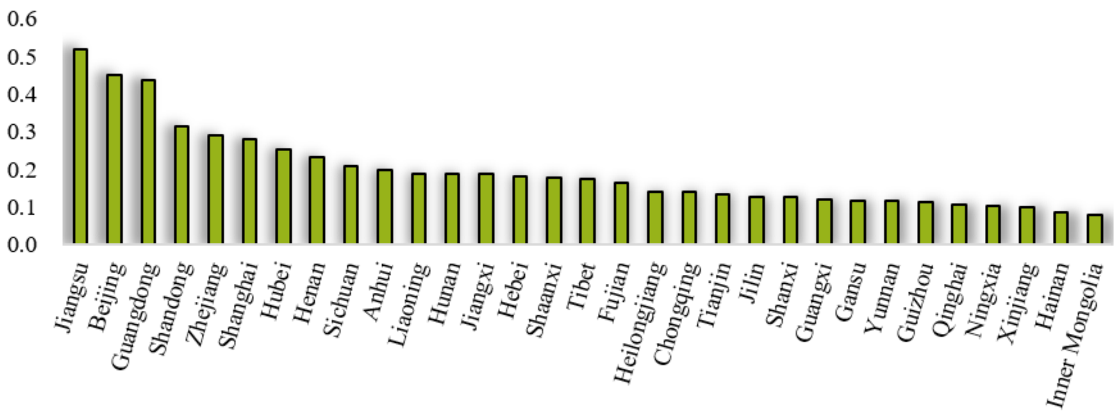

Fig. 4 Organizational level.

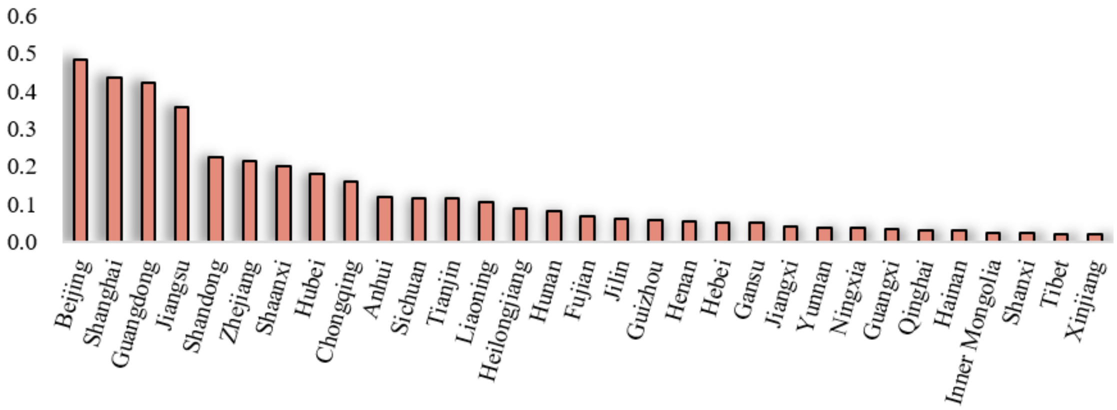

Fig. 5 Environmental level.

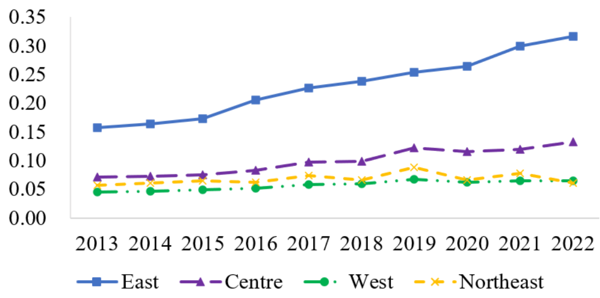

Fig. 6 Technical levels of the four regions.

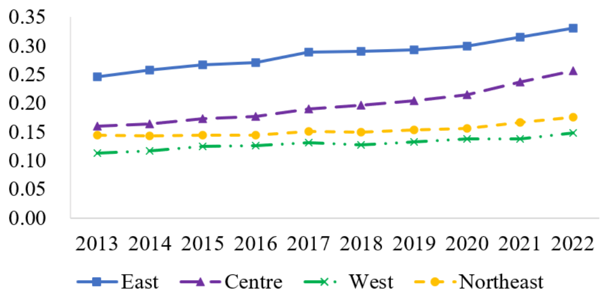

Fig. 7 Organizational levels of the four regions.

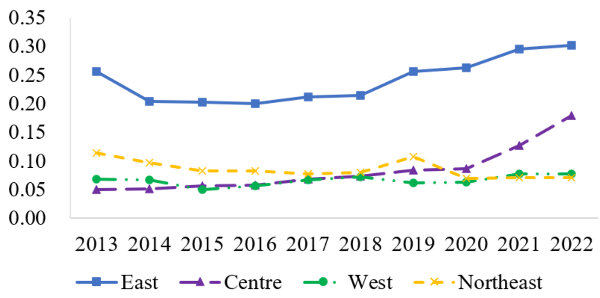

Fig. 8 Environmental levels of the four regions.

3) Development Level of Each Dimension

This subsection provides a comprehensive quantitative analysis of the four core dimensions of NQL, NQLM, NQLO, and NQDE in manufacturing in each province. The measurement results are shown in Table III.

In terms of the NQL dimension, Beijing, Guangdong, and Jiangsu are leading. Economically developed regions have high education levels, attract and cultivate outstanding talents, and form agglomeration effects. In contrast, Hainan, Ningxia, and Inner Mongolia lag behind due to various factors such as economy, education, and talent. In the NQLO dimension, Jiangsu, Guangdong, and Beijing are leading, thanks to their developed economy, strong investment, complete industrial chain, and policy support. In the NQLM dimension, Guangdong, Jiangsu, and Zhejiang perform well, with large technological innovation and R&D investment and mature industrial clusters. Qinghai, Hainan, and Tibet lag due to natural conditions, infrastructure and industrial structure, and other factors. In terms of the NQDE dimension, Beijing, Shanghai and Guangdong promote high-quality development in manufacturing and attract foreign investment and technology. Shanxi, Tibet, and Xinjiang face challenges but are taking measures to promote the transformation and upgrading in manufacturing. Shanxi transforms to high-end manufacturing, Tibet develops green industries, and Xinjiang strengthens scientific and technological innovation and industrial cluster construction.

Overall, in the development of NQPF in China's manufacturing, the dimension of NQLO is the most prominent, followed by NQL, with the NQDE coming in a close second, while the growth rate of NQLM is relatively slow. Given the slow development of NQLM, we should increase R&D investment and encourage technological innovation to promote the replacement of labor material and improve efficiency.

B. Analysis of Regional Disparities

We use the Dagum Gini coefficient method to analyze the regional disparities and contribution rates in the development of NQPF in manufacturing in four regions. The rise and fall of the Gini coefficient reflect the increase or decrease in the inequality of productivity distribution, respectively, as shown in Table IV. The overall Gini coefficient fluctuated and increased slightly from 2013 to 2018. It rose year by year after 2019, from 0.377 to 0.425, indicating that the productivity growth rate is uneven and the gap is widening between regions.

As seen in Table 4, during the period 2013-2022, the between-group contribution has stabilized at around 70%, the within-group at around 20%, the hypervariable density is less than 10%, and the between-group contribution (G_b) is significantly higher than the within-group (G_w), indicating that inter-regional disparities in productivity are the main cause of overall inequality.

TABLE IV
DAGUM GINI COEFFICIENT AND ITS DECOMPOSITION

Year	Total	Dagum Gini coefficient			Contribution		
		G_w	G_b	G_t	G_w%	G_b%	G_t%
2013	0.350	0.069	0.257	0.024	19.694	73.370	6.936
2014	0.348	0.072	0.244	0.032	20.668	70.074	9.258
2015	0.353	0.073	0.253	0.027	20.628	71.716	7.655
2016	0.370	0.076	0.266	0.028	20.570	71.935	7.495
2017	0.369	0.076	0.259	0.034	20.684	70.124	9.192
2018	0.382	0.081	0.265	0.036	21.259	69.328	9.413
2019	0.377	0.079	0.269	0.030	20.831	71.274	7.895
2020	0.407	0.087	0.284	0.035	21.466	69.926	8.608
2021	0.420	0.088	0.295	0.037	20.995	70.205	8.800
2022	0.425	0.087	0.296	0.041	20.557	69.681	9.762

From Fig. 9, the eastern region has the highest Gini coefficient, showing that its internal development imbalance is significant. The western region is second, and the central and northeastern regions have relatively low intra-group Gini coefficients. A gradient development pattern has been formed with the east leading, the central region second, the northeastern region following, and the west lagging.

Fig. 10 shows that the differences between the eastern region and the other three regions are relatively large, reflecting the significant development gap between the eastern region and the other regions. The inter-regional differences in the Gini coefficients between central and western, central and northeastern, and western and northeastern have increased year by year since 2019, indicating that the development level of NQPF in manufacturing among different regions has become increasingly intense. In terms of the average value of the Gini coefficient from 2013 to 2022, the difference between east-west (0.419) is the largest, followed in order by east-northeast (0.358), east-central (0.342), central-west (0.220), west-northeast (0.206), and central-northeast (0.150).

C. *Spatiotemporal Evolution Characteristics*

1) *Characteristics of Temporal Evolution*

We adopt the kernel density estimation method to analyze the evolutionary characteristics of NQPF in manufacturing in four regions from 2013 to 2022. To keep the graph clear, we select the kernel density distribution at four time points in 2013, 2016, 2019, and 2022 for display.

Observing Fig. 11, the center of the curve shifts to the right year by year, showing that the level of NQPF in manufacturing continues to improve. The peak of the wave decreases, the width increases, and the right tail lengthens, indicating that the development gap between provinces is widening.

Fig. 12 (a) shows that the productivity level in the eastern region has increased, and the curve has shifted to the right. Its waveform shifts from multiple peaks to single peaks, but the multiple peaks weaken, reflecting a polarization phenomenon. The peak value decreases, the width increases, and the right-tailing phenomenon indicates that the provincial gap within the region is increasing.

In Fig. 12 (b), the productivity level in the central region is rising but unstable, the peak of the curve fluctuates, the horizontal width increases, and the center shifts to the right. The single-peak distribution and the absence of significant tailing indicate that the productivity levels of the central provinces are similar and not very different.

Fig. 12 (c) shows, the curve first moves to the right and then to the left, this phenomenon shows that the level of NQPF in manufacturing in the western region first increased and then declined. The fluctuation range is large and the trailing phenomenon is significant, which means that the level of NQPF in manufacturing in each province the gap is widening. However, the peak is generally decreasing and the broadband is increasing, indicating that the level of NQPF in manufacturing in the western region is also slowly rising.

Fig. 12 (d) shows that the kernel density curve in the Northeast region has also experienced changes from right to left, indicating that the development of NQPF in manufacturing is also facing fluctuations and gaps, which may be affected by the uneven industrial layout. In general, the peak value decreases, the bandwidth expands, the unimodal distribution is maintained, and no polarization phenomenon is seen.

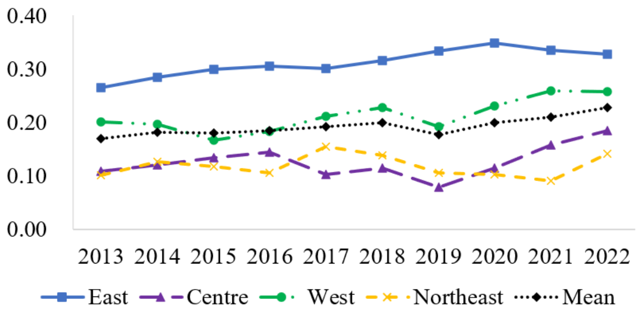

Fig. 9 G_w difference results.

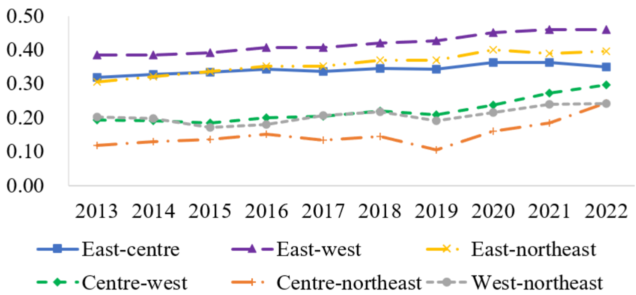

Fig. 10 G_b differences results.

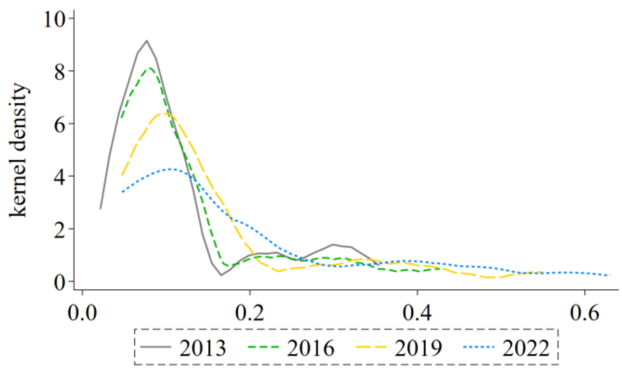

Fig. 11 National area.

2) Characteristics of Spatial Evolution

Based on kernel density estimation, we further analyze the dynamic evolution process of NQPF in manufacturing by using a Markov chain. Drawing on the research of Wang et al. [37] and Sutisna et al. [38], the analysis is carried out from the traditional Markov chain and spatial Markov chain respectively. The results are shown in Tables V and VI.

Table V shows that NQPF evolution is strongly self-sustaining. Low-level provinces (state 1) maintain the status quo with a high probability of 88.89%, only 9.72% probability of upgrading to a lower level (state 2), and no cross-level transition (transition probability to state 3 and state 4 is 0). Low and medium level provinces (state 2) have both upgraded (14.29% transition state 3) and downgraded risk (7.14% transition state 1), reflecting vulnerability during the transition window. The stability of medium-high (state 3) and high-high (state 4) provinces increases (self-maintenance rate 80.82% and 98.44% respectively), but the medium-high level still faces 8.22% degradation risk, while the high-level degradation probability is only 1.56%. This confirms the gradual nature and hierarchical barriers to productivity growth.

The spatial Markov matrix (Table VI) reveals the moderating effect of the neighborhood environment. Locking effect of inefficient neighborhood (type 1). When the province is surrounded by low-level neighbors, 100% of low-level and medium-low-level enterprises remain unchanged, completely inhibiting the possibility of natural escalation by 9.72%, forming a “geographical poverty trap”.

Leverage in medium neighborhood (type 2-3). In the middle efficiency neighborhood, the probability of upgrading from middle and low-level provinces (state 2) to middle and high-level provinces (state 3) is significantly increased to 12.00% (type 2) and 21.43% (type 3), which is up to 50% higher than the global average (14.29%), highlighting the catalytic value of medium clusters for productivity jump.

Competitive suppression of efficient neighbors (type 4). Although the high-level provinces themselves are perfectly stable, the medium-to-high-level provinces surrounded by high-efficiency neighborhoods (state 3) face a 2.50% risk of degradation (transition state 2) and a 0% probability of escalation, reflecting the “benchmark squeeze effect”.

In general, (1) the level of neighborhood type affects the development of NQPF in the province. Low-level neighborhoods have little impact on the local area and have a low transfer probability. (2) at lower, higher, and high-level neighborhood types, the level of NQPF in manufacturing remains stable, showing the characteristics of “club convergence”, and the diagonal probability is much higher than the non-diagonal line. (3) The development level of NQPF in manufacturing is coordinated with adjacent regions. When the neighborhood is low, the number of transfers is low. When the neighborhood is high, the number of transfers increases significantly.

To verify whether the neighborhood type has a spatial lag effect on the level of NQPF in China’s manufacturing, refer to the research of Wang et al. [37]for testing. The test results show that the neighborhood type has a significant spatial spillover effect on the development level of NQPF in China’s manufacturing.

TABLE V
TRADITIONAL MARKOV TRANSITION PROBABILITY MATRIX

t/t+1	*n*	1	2	3	4
1	72	0.8889	0.0972	0.0139	0.0000
2	70	0.0714	0.7857	0.1429	0.0000
3	73	0.0000	0.0822	0.8082	0.1096
4	64	0.0000	0.0000	0.0156	0.9844

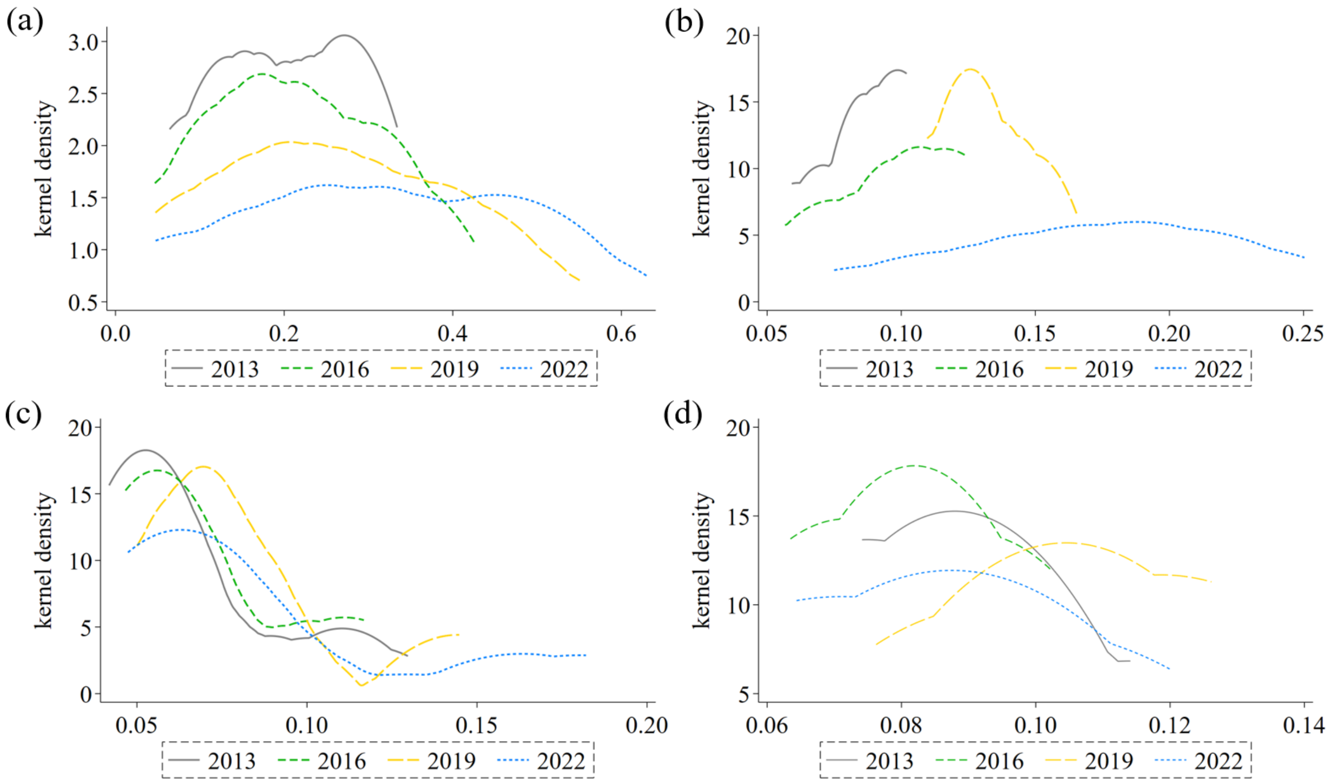

Fig. 12 Kernel density map, (a) is the eastern region, (b) is the central region, (c) is the western region, (d) is the northeast region.

TABLE VI
SPATIAL MARKOV TRANSITION PROBABILITY MATRIX

Type	*t/t+1*	*n*	1	2	3	4
1	1	8	1.0000	0.0000	0.0000	0.0000
	2	8	0.0000	1.0000	0.0000	0.0000
	3	0	0.0000	0.0000	0.0000	0.0000
	4	0	0.0000	0.0000	0.0000	0.0000
2	1	50	0.8800	0.1000	0.0200	0.0000
	2	25	0.1200	0.7600	0.1200	0.0000
	3	26	0.0000	0.0769	0.8846	0.0385
	4	10	0.0000	0.0000	0.0000	1.0000
3	1	5	0.8000	0.2000	0.0000	0.0000
	2	14	0.0714	0.7143	0.2143	0.0000
	3	24	0.0000	0.1250	0.7917	0.0833
	4	14	0.0000	0.0000	0.0000	1.0000
4	1	9	0.8889	0.1111	0.0000	0.0000
	2	23	0.0435	0.7826	0.1739	0.0000
	3	23	0.0000	0.0435	0.7391	0.2174
	4	40	0.0000	0.0000	0.0250	0.9750

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study innovatively integrates the TOE theory with Marx's productivity theory, and constructs an evaluation system, revealing the internal structural contradiction of "technological lag, organizational dominance, environmental fluctuations" in the manufacturing NQPF, making up for the lack of attention paid to the technology dimension and regional differentiation in existing research. Through the spatial Markov chain empirical verification of "club convergence" and competition inhibition effects, it provides new evidence of complex spatial interaction for regional development theory. We draw the following conclusions:

(1) The overall NQPF in China's manufacturing is on an upward trend, but regional development shows a gradient pattern of "the eastern region leading, the central region following, the northeastern region trailing, and the western region lagging". In addition, the regional gap continues to widen, and the inter-group difference contribution rate exceeds 70%, which is the main reason.

(2) Structural contradictions are revealed under the TOE theory. The technical level has become a key shortcoming, especially the slowest growth rate of NQLM, reflecting the lack of independent innovation of core technologies and the bottleneck of green technology transformation. The relative advantages at the organizational level are prominent, and high-quality talents and efficient industries synergize to form the core support for current upgrading. The environmental level fluctuates significantly, and policy stability and market resilience are crucial to transformation.

(3) Spatial evolution shows the risk of "club convergence" and polarization. Low-level provinces are restricted from development by backward neighbors, while high-level regions are highly stable. In addition, high-level neighboring provinces have a competitive inhibitory effect on neighboring low-level provinces, highlighting the double-edged sword nature of spatial spillover.

B. Recommendations

(1) In view of the technical shortcomings, it is necessary to set up a national special fund to tackle the "bottleneck" technology, improve the innovation risk sharing mechanism, and strengthen the integration platform of industry, academia, research, and application.

(2) Given the regional differentiation and imbalance, a coordinated strategy should be implemented in a differentiated manner: the eastern region should strengthen radiation and drive, the central region should undertake industrial transfer, and the western and northeastern regions urgently need talent policies and infrastructure tilt. The western and northeastern regions should focus on supplementing digital infrastructure and implementing the "eastern technology, local transformation" assistance model.

(3) Establish a cross-regional factor circulation platform to break down club barriers. Consolidate organizational advantages, cultivate smart manufacturing talents in a targeted manner, and optimize the assessment mechanism of innovation carriers. Stabilize environmental support, maintain the continuity of open policies and cultivate a green consumer market.

C. Significance

This study has certain practical significance for governments and manufacturing enterprises to improve the NQPF in manufacturing.

(1) Government decision-making level. Provide a targeted basis for regional coordination policies, clarify the priority of technological breakthroughs, and establish a cross-domain cooperation mechanism (such as an enclave economy). Warning of the risk of widening regional gaps, promoting the establishment of a precise assistance system based on technology spillover and talent sharing, and avoiding the solidification of the Matthew effect.

(2) Manufacturing enterprise level. Reveal that technology investment (green and digital technology) is the core path for enterprises to break through the bottleneck of upgrading, and guide resources to the R&D end. It is suggested that regional layout strategies need to consider spatial spillover characteristics: enterprises in high-level areas can take advantage of agglomeration advantages, while low-level enterprises need to leverage policy dividends to break through neighborhood restrictions.

D. Future Research

Our existing indicators do not cover the core connotation of NQPF comprehensively enough, and some indicators have duplication or ambiguous attribution problems. Secondly, the singleness of the method is more prominent. Although the Entropy-TOPSIS method can handle multi-attribute decision-making, it cannot distinguish the nonlinear relationship between indicators. The Markov chain assumes "no aftereffect", ignoring the dynamic impact of regional policies or emergencies on exogenous shocks. Furthermore, it is now 2025, but the research data only goes up to 2022, which has a certain lag. In the next study, we will improve these research defects and shortcomings.

TABLE I
EVALUATION INDEX SYSTEM OF NQPF IN MANUFACTURING USING TOE THEORY

Levels	Dimensions	Primary indicators	Secondary indicators	Quantification method
T	NQLM	digitalization level	digital infrastructure	popularization rate of mobile phones
				broadband subscribers port of internet
				number of domain names
				capacity of mobile phone exchanges
			digital technology application	income from software related business
				income from IT services
				number of employees in urban units of information transmission, software, and information technology
		technological innovation capacity	technological input	full-time equivalent of R&D personnel
				R&D personnel
				expenditure on new products development
				expenditure for acquisition of foreign technology
				expenditure for technical renovation
				intramural expenditure on R&D
			technological output	number of effective invention patents
				projects for new products development
				R&D projects of industrial enterprises above designated size
				sales revenue of new products
		green development level	pollution emission	industrial wastewater cod discharged
				industrial waste gas nitrogen oxides emission
			pollution control	industrial wastewater treatment capacity
				industrial waste gas treatment capacity
				common industrial solid wastes integrated rate
O	NQL	new quality human resources	training environment	ratio of education expenditure to GDP
				number of regular HEIs
				number of educational personnel in HEIs
				ratio of expenditure on R&D in higher education to basic research expenditure
			quality structure	graduates of doctor's degree postgraduates
				average education enrolment in higher education per 100,000 population
				annual average employees in manufacturing
	NQLO	new quality industrial development level	collaborative environment	number of innovative industrial clusters
				number of national Hi-tech zones
				number of tenants of technology business incubators
				number of tenants of national university science parks
			industrial structure	ratio of secondary industry product to gross regional product
				increase in number of manufacturing enterprises
				total profit to business revenue of manufacturing enterprises
				percentage of enterprise with R&D activities to total number of enterprises
E	NQDE	level of open cooperation	degree of opening up	number of foreign technology import contracts
				value of foreign technology import contracts
				contract inflows to domestic technical markets
				contract exportation from domestic technical markets
		social support strength	government fiscal supply	ratio of government funds to manufacturing R&D expenditure
			market demand	transaction value in technical markets

"R&D" stands for Research and Development. "GDP" stands for Gross Domestic Product. "COD" is an abbreviation or Chemical Oxygen Demand, which is a measure of the oxygen that would be required to oxidize pollutants in water. "HEIs", the full form is "Higher Education Institutions", which refers to institutions that provide higher education.

TABLE II
DEVELOPMENT LEVEL OF NQPF IN CHINA'S MANUFACTURING FROM 2013 TO 2022

Province	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Average
Guangdong	0.317	0.316	0.361	0.427	0.445	0.499	0.550	0.612	0.635	0.630	0.479
Jiangsu	0.334	0.330	0.351	0.352	0.412	0.396	0.430	0.440	0.486	0.522	0.405
Beijing	0.265	0.277	0.286	0.301	0.322	0.335	0.376	0.384	0.424	0.443	0.341
Shanghai	0.290	0.255	0.228	0.277	0.282	0.303	0.333	0.283	0.348	0.340	0.294
Zhejiang	0.209	0.190	0.204	0.220	0.240	0.264	0.299	0.330	0.375	0.414	0.275
Shandong	0.213	0.211	0.209	0.211	0.226	0.227	0.229	0.276	0.311	0.353	0.247
Hubei	0.101	0.109	0.120	0.124	0.139	0.149	0.166	0.169	0.205	0.250	0.153
Fujian	0.094	0.093	0.098	0.137	0.182	0.168	0.166	0.134	0.157	0.163	0.139
Sichuan	0.106	0.105	0.109	0.117	0.123	0.136	0.144	0.158	0.164	0.178	0.134
Anhui	0.090	0.094	0.101	0.125	0.124	0.127	0.142	0.150	0.175	0.204	0.133
Shaanxi	0.096	0.101	0.103	0.103	0.113	0.121	0.145	0.147	0.176	0.182	0.129
Henan	0.102	0.105	0.111	0.117	0.121	0.124	0.140	0.140	0.148	0.163	0.127
Hebei	0.119	0.115	0.116	0.115	0.140	0.131	0.122	0.114	0.133	0.146	0.125
Chongqing	0.130	0.122	0.085	0.113	0.153	0.153	0.087	0.111	0.121	0.129	0.120
Hunan	0.102	0.093	0.096	0.098	0.111	0.109	0.122	0.122	0.144	0.191	0.119
Liaoning	0.114	0.114	0.110	0.102	0.125	0.114	0.111	0.110	0.115	0.120	0.114
Tianjin	0.110	0.101	0.089	0.087	0.082	0.082	0.086	0.091	0.103	0.108	0.094
Jiangxi	0.064	0.067	0.070	0.072	0.085	0.098	0.110	0.112	0.121	0.132	0.093
Heilongjiang	0.074	0.076	0.080	0.080	0.080	0.079	0.076	0.072	0.077	0.078	0.077
Jilin	0.076	0.065	0.065	0.063	0.063	0.061	0.126	0.071	0.092	0.064	0.075
Shanxi	0.059	0.057	0.056	0.057	0.083	0.077	0.115	0.089	0.074	0.075	0.074
Tibet	0.066	0.081	0.080	0.072	0.079	0.073	0.075	0.072	0.071	0.073	0.074
Guangxi	0.057	0.056	0.060	0.063	0.078	0.082	0.092	0.081	0.081	0.078	0.073
Guizhou	0.059	0.055	0.058	0.058	0.064	0.060	0.068	0.069	0.078	0.075	0.064
Yunnan	0.054	0.052	0.057	0.056	0.071	0.072	0.080	0.065	0.063	0.066	0.064
Gansu	0.051	0.051	0.054	0.056	0.057	0.059	0.073	0.057	0.059	0.063	0.058
Ningxia	0.049	0.048	0.054	0.047	0.052	0.050	0.057	0.053	0.050	0.057	0.052
Xinjiang	0.042	0.043	0.048	0.051	0.056	0.052	0.060	0.050	0.051	0.054	0.051
Qinghai	0.047	0.054	0.051	0.054	0.053	0.052	0.050	0.050	0.048	0.047	0.050
Inner Mongolia	0.049	0.047	0.044	0.047	0.047	0.048	0.054	0.052	0.051	0.054	0.049
Hainan	0.064	0.042	0.044	0.047	0.044	0.045	0.047	0.047	0.047	0.048	0.048
Average	0.116	0.114	0.116	0.124	0.137	0.140	0.153	0.152	0.167	0.177	0.140

TABLE III
DEVELOPMENT LEVEL OF NQPF IN CHINA'S MANUFACTURING IN EACH DIMENSION

Province	NQL		NQLO		NQLM		NQDE	
	Average	Rank	Average	Rank	Average	Rank	Average	Rank
Beijing	0.525	1	0.35	3	0.257	4	0.483	1
Tianjin	0.136	20	0.134	19	0.072	17	0.116	12
Hebei	0.184	13	0.175	14	0.128	8	0.051	20
Shanxi	0.133	22	0.114	20	0.07	18	0.024	29
Inner Mongolia	0.082	31	0.073	28	0.048	25	0.024	28
Liaoning	0.182	14	0.193	12	0.094	14	0.105	13
Jilin	0.141	19	0.112	22	0.059	21	0.061	17
Heilongjiang	0.141	18	0.142	18	0.05	24	0.088	14
Shanghai	0.225	9	0.325	6	0.228	6	0.438	2
Jiangsu	0.377	3	0.712	1	0.391	2	0.358	4
Zhejiang	0.252	5	0.331	5	0.287	3	0.214	6
Anhui	0.178	15	0.215	8	0.12	9	0.119	10
Fujian	0.169	16	0.157	17	0.149	7	0.068	16
Jiangxi	0.159	17	0.212	9	0.074	16	0.041	22

Province	NQL		NQLO		NQLM		NQDE	
	Average	Rank	Average	Rank	Average	Rank	Average	Rank
Shandong	0.292	4	0.336	4	0.235	5	0.223	5
Henan	0.248	6	0.203	11	0.112	11	0.054	19
Hubei	0.242	7	0.262	7	0.109	13	0.181	8
Hunan	0.192	11	0.18	13	0.109	12	0.081	15
Guangdong	0.411	2	0.453	2	0.51	1	0.422	3
Guangxi	0.136	21	0.094	25	0.069	19	0.034	25
Hainan	0.101	29	0.067	30	0.038	29	0.029	27
Chongqing	0.123	26	0.157	16	0.087	15	0.16	9
Sichuan	0.209	10	0.209	10	0.119	10	0.117	11
Guizhou	0.132	24	0.083	27	0.051	23	0.057	18
Yunnan	0.122	27	0.107	23	0.054	22	0.039	23
Tibet	0.227	8	0.039	31	0.032	31	0.021	30
Shaanxi	0.184	12	0.17	15	0.068	20	0.2	7
Gansu	0.133	23	0.094	24	0.038	28	0.051	21
Qinghai	0.126	25	0.071	29	0.036	30	0.032	26
Ningxia	0.091	30	0.112	21	0.038	27	0.037	24
Xinjiang	0.111	28	0.086	26	0.042	26	0.02	31
Average	0.192		0.193		0.122		0.127	

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