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Research article

How environment and technology affect the regional manufacturing industry development

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ABSTRACT

To help the manufacturing industry achieve high-quality development, it is urgent to identify the factors that affect the development of regional manufacturing. Compared to previous regression models, this article attempts to discover the nonlinear effects of different factors on regional manufacturing industry development (RMID) and their future impact trends. Based on the theory of new structural economics, we used order parameter analysis to examine the impact of environmental pollution and technology on RMID. The results indicate that: (1) The half of the cities promote industrial growth, but there are still three other situations: development slow down (3/21), a slight downward trend (5/21), and recession (2/21). (2) The two-thirds of cities adopt green development to promote industrial growth, while the development of other cities slows down (3/21), and some cities have a slight downward trend (4/21). The conclusion is as follows: (1) Through comparison, it is found that the impact of environment and technology on the RMID remains roughly synchronous, but currently the environmental promotion effect is greater. (2) We have found four technological development paths and can extend three green development models, effectively promoting RMID's green technology development. These suggestions will lay the foundation for promoting RMID.

1. Introduction

The manufacturing industry is the lifeline of the national economy and a pillar industry for national economic development. It can leverage economies of scale to drive overall industrial productivity and is an important engine of economic development. In this context, the development of manufacturing has received attention from various countries. The development of the manufacturing industry should transform from a traditional single-economic factor-driven approach to an innovation-driven and green development mode [1,2]. On the one hand, the high-quality development of the manufacturing industry cannot be ignored. The bottom line is to implement green development, and environmental issues have become an important reason to suppress the development of the manufacturing industry. The government should ensure the rational utilization and development of resources and reduce the impact of manufacturing on the resource environment. On the other hand, technological development is one of the main directions for high-quality development in the manufacturing industry, including production technology, service technology, business management

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technology, and other aspects of the industry.

Environmental development. In the current global economic landscape, green development has become the core concept leading future sustainable development. With the profound understanding of the consequences of environmental destruction by humans and the serious constraints of environmental pollution on economic and social development, the importance of green development is increasingly prominent. Green development advocates reducing energy consumption and waste generation in the production process, thereby achieving a win-win situation between economic development and resource protection. In addition, green development requires the transformation of economic structure towards a more environmentally friendly, energy-saving, and low-carbon direction. Many scholars have confirmed the importance of environmental development [3–8]. In RMID, a green environment requires the manufacturing industry to achieve clean production in the production process, reduce pollutant emissions, and improve resource utilization efficiency. On the one hand, with the increasing awareness of environmental protection among consumers and the growing demand for green products. Manufacturing enterprises must produce more products that meet green standards to meet market demand. On the other hand, the government's policy support and strengthened regulatory efforts for green development provide strong guarantees for the green transformation of the manufacturing industry. This can encourage enterprises to engage in green innovation and upgrading. Moreover, it can limit and eliminate enterprises that do not meet environmental standards, thereby promoting the transformation of the entire industry towards green development. This has effectively promoted the transformation of RMID towards a green development.

Technological development, as the core driving force for modern social progress, is not only important in the economic field, but also runs through various aspects of social life. In the context of globalization, the importance of technological development is particularly prominent. It is not only a key factor in national competitiveness, but also an important means of promoting sustainable development. By improving production efficiency, reducing production costs, and creating new market demands, technological innovation can provide strong impetus for economic development. Many scholars have confirmed the importance of technological development [9–11]. The development of various technologies has become a driving force for the manufacturing industry [12–14]. In RMID, technological development has had a profound impact on production methods. The application of automation and robotics technology has reduced manual labor, improved production efficiency and product quality. Advanced technology makes the production process more intelligent, achieving real-time monitoring and optimization of the production process. It not only enhances the competitiveness of the manufacturing industry, but also provides support for its sustainable development.

It is worth noting that, the mainstream theories in the industry currently include the Political- Economical-Social-Technological (PEST) theory, Strengths-Weaknesses-Opportunities-threats (SWOT) theory, and the Diamond theory. However, most of the existing theories ignore the dynamics of RMID. Therefore, we use new structural economics (NSE) theory to explore RMID and its affecting factor, that is, environmental pollution and technology. On the other hand, the mainstream methods in the industry currently include econometric regression and evaluation systems. However, most of the existing methods cannot characterize the dynamic trend of RMID. To solve this problem, under the NSE framework, we use the order parameter method to capture the dynamic trend of RMID.

The contribution of this article is as follows: (1) Theoretical advantages. In view of the findings obtained by previous studies, we use NSE theory to study the impacts of environmental pollution and technology on RMID. Only in this way can we better ensure manufacturing-development sustainability. Therefore, this paper brings the relevant factors into the theoretical framework and makes an in-depth study. (2) The advantages of the method. The order parameter method can not only calculate the trend of various variables, including promotion, inhibition, and event reception. By using this method, it is also possible to effectively identify the trends and differences in the impact of different urban environments and technological variables on RMID.

2. Literature review

2.1. Development of the manufacturing industry

The manufacturing industry is an important component of a country's socio-economic structure, which has attracted considerable attention. Liang et al. [15]and Ming et al. [16] analyzed the competitiveness of regional manufacturing and equipment manufacturing, respectively. They focused on which factors affect RMID. In terms of research method, Ren et al. [17] analyzed the manufacturing competitiveness of different countries. Ocampo et al. [18] used structural equations to study the competitiveness of the Central American processing industry. However, these studies on RMID mainly use the regression equation method and structural equation method. Although these methods can explore the relationships and influences between variables, in a complex environment they ignore the dynamic-evolution process of manufacturing transformation. Han et al. [19] found that there are regional differences in constraints for the manufacturing industry. Lin et al. [20] evaluated the manufacturing industry from both regional and industry levels and found that coastal areas and heavy manufacturing scored relatively high.

2.2. Factors influencing the manufacturing industry

The traditional manufacturing industry has caused great damage to and consumption of the environment and resources, which has led governments to emphasize development while also paying attention to ecological environment protection. Therefore, emphasizing environmental protection and sustainable development is crucial [21–26]. Green development can effectively reduce pollution and resource waste generated by enterprises during the production process. For example, Zhang [27] found that China's manufacturing industry still needs to improve in the reduction of pollution emissions. Lian et al. [28] found that the Chinese manufacturing industry tends to move from provinces with strict regulation to provinces with loose regulation. Wu et al. [29] believe that controlling environmental pollution is the key to affecting manufacturing development. Lena et al. [30] found that environmental policies have no negative impact on productivity in most manufacturing industries in Italy. Mani et al. [31] and Ederington et al. [32] found that environmental regulation will bring additional costs to enterprises and will hurt their competitiveness. Sun et al. [33] and Shen et al. [34] found that the manufacturing industry in a province is significantly affected by environmental factors. Sheng et al. [35] found that the purpose of environmental regulations is not to relocate polluting industries, but to encourage enterprises to improve the quality of their products, thereby increasing their productivity. Ye et al. [36] found that green-industry policy can promote the TFP of manufacturing enterprises. Zhu et al. [37] studied the carbon-reduction effects of green-technology-innovation subsidies and carbon-emission trading on manufacturing enterprises. When manufacturing focuses on reducing its impact on the environment, it will achieve the greatest social benefits. Xie et al. [38] believes that environmental regulation is not a single effective means to reduce pollution and overcapacity in the manufacturing industry. However, it is worth noting that targeted policies need to be formulated for different segmented industries. An et al. [39] found that environmental regulations can promote manufacturing agglomeration. However, as the prediction period prolongs, the promoting effect transforms into an inhibitory effect.

In the current era, high-quality manufacturing cannot be separated from technological and innovation-driven manufacturing. By using technological innovation as the driving force to promote economic development from a resource-element-oriented to a technological-innovation-oriented approach, the overall efficiency of the industry can be improved. For example, Youssef et al. [40] believed that time-based technology will pave the way for the next generation of intelligent manufacturing and become its main pillar. Wang et al. [9] found that AI technology can improve the total factor productivity (TFP) of manufacturing enterprises. Kaur et al. [10] found that technology accumulation has a promoting effect on the productivity of manufacturing enterprises, especially the stock of nonphysical imported technology. Das et al. [41] studied the relationship between advanced manufacturing technology and RMID. Dou et al. [42] studied the impact of technological development on manufacturing demand. They found that technology can improve production efficiency. Liu et al. [43] found that mobile information technology has a direct impact on the service-innovation capabilities of manufacturing enterprises. Lee [44] found that enterprise-intelligent manufacturing technology has a beneficial impact on achieving business diversification. Ronaghi [45] discovered that artificial intelligence technology can change manufacturing processes. Huang et al. [46] found that the impact of intelligent development on the TFP of manufacturing enterprises is generally positive. Sarbu [47] studied the impact of Industry 4.0 on the innovation of manufacturing enterprises. It found that new technologies can promote product innovation in enterprises. Kim et al. [48] found that adopting front-end technology can have an impact on the existing business growth of manufacturing enterprises. When enterprises develop new businesses, adopting basic technologies will have a positive impact on their growth.

Previous literature has confirmed that environment and technology can significantly promote the development of manufacturing industry, but due to limitations in research perspectives and methods, few people understand the impact of environment and technology on the future development trend of RMID. The RMID is a dynamic and uncertain process that urgently requires relevant theoretical guidance and new research methods to solve.

2.3. Related theory

Mainstream theories in the industry currently include the PEST, SWOT, and Diamond theories. In terms of PEST theory, Du [49] applied this theory to conduct a systematic analysis of the Chinese automotive parts industry in order to provide suggestions for relevant enterprises. Khatami et al. [50] used this theoretical framework to analyze the food industry in the context of globalization. In terms of SWOT theory, Chen [51] used SWOT to systematically analyze the home textile industry in Hebei. Then, he identified its existing problems and put forward countermeasures. Sevkli et al. [52] used SWOT theory to analyze the Turkish aviation industry and provide valuable insights for its strategic management decisions. In terms of Diamond theory, Zhu et al. [53] used the Diamond theory for reference when describing the status of aviation-industry competitiveness and put forward a competitiveness evaluation system. Zhou [54] used the Diamond theory to evaluate the aviation logistics industry. Allen et al. [55] used the Diamond theory to evaluate the green building complex in Portland, to give full play to the potential of clustered economic development. Dou et al. [56] used this theoretical framework to study the influencing factors of manufacturing in G20 countries.

The existing theories ignore the dynamic trends between variables affecting RMID. To solve this problem, the new structural economics (NSE) theory is used to study RMID.

3. Methodology

3.1. Research theory and variables

The NSE theory framework is widely used in other disciplines. Dou et al. [57] used it to analyze the different stages of manufacturing development. Lin [58] used it to study the determinants of economic structure and its evolution. These studies reflect the strong support characteristics of the NSE theory. In view of the findings obtained by previous studies, we use this theory to study the impacts of environmental pollution and technology on RMID. Only in this way can we better ensure manufacturing-development sustainability. Therefore, this paper brings the relevant factors into the theoretical framework and makes an in-depth study.

There are three main variables examined in this article: RMID, environment, and technology. This article provides the following descriptions.

RMID variables need to objectively reflect the overall development of manufacturing. For example, Zheng et al. [59] used the proportion of industrial added value (X1) and GDP (X2) to reflect it, i.e., X1/X2. Therefore, they can be taken to be RMID variables.

Environmental variables need to objectively reflect the effects of the degree of pollution caused by local manufacturing on the environment. The solid production discharge (X3), wastewater discharge (X4), and exhaust emissions (X5) of the per-unit industrial added value can reflect the environmental pollution [12,13], namely Score = entropy{X3, X4, X5}. Therefore, we used an entropy algorithm to process the above indicators to obtain a comprehensive index of environmental pollution. Therefore, we take these as environmental pollution variables.

Technical variables need to objectively reflect the research and development intensity of the local manufacturing industry. Bravo-Ortega et al. [60] used the proportion of internal expenditure on R&D (X6) and the industrial total value (X7) to reflect the R&D intensity, i.e., X6/X7. Therefore, these can be taken as technology variables.

3.2. *Research method*

The Haken model [61] is based on the theory of synergetics and uses mathematical models to mathematically express the process of system evolution. Assuming that changes in the external environment will not affect sudden or large-scale changes in various parts of the system, the interaction mechanism of various factors within the system determines whether the industry can transform towards a more advanced and orderly direction. The influencing factors in the Haken model are divided into two types: fast and slow variables, among which the dominant variable is called the order parameter.

The model has the following assumptions.

Assumption 1. There is correlation between variables

Assumption 2. The model has Markov property

Assumption 3. Dependence or inhibitory effects between variables are independently achieved by changing their own rate of change

According to the Markov principle, variables are represented by the following difference equation (1) and nonlinear differential equation (2):

$$E_i(k+1)=\widetilde{f}_i(E_1(k),E_2(k),\dots,E_n(k)) \tag{1}$$

$$\dot{E}_i(t)=f_i(E_1(t),E_2(t),\dots,E_n(t)) \tag{2}$$

Where, E represents that the variable is represented by a time series $E=(E_1E_2,\dots,E_n)$, $i=1,2,\dots,n,k=1,2,\dots,m-1$, $\widetilde{f}$ is a nonlinear mapping, f is a nonlinear function. Due to the uncorrelation between variables, f takes the following form equation (3):

$$f_i(E_1(t),E_2(t),\dots,E_n(t))=[\alpha_i+\delta_i(E_1(t),E_2(t),\dots,E_n(t))]E_i(t) \tag{3}$$

α_i represents the inherent rate of change of $E_i(t)$, which is a damping coefficient of $E_i(t)$ and satisfies $\alpha_i\neq 0$, $\delta_i(E_1(t),E_2(t),\dots,E_n(t))$ is the characterization function of each variable for $E_i(t)$. When all variables are 0, there is $\delta_i(0,0,\dots,0)=0$, indicating that the influence of the independent variable on the dependent variable is 0.

The linear term can be separated from the right end of formula (3), and the order parameter model can be represented by an autonomous differential equation:

$$\dot{E}_i(t)=f_i(E_1(t),E_2(t),\dots,E_n(t))=\alpha_iE+\delta_i(E_1(t),E_2(t),\dots,E_n(t))E_i \tag{4}$$

Let $\dot{E}_i(t)=0$, obviously the origin of $E_i^*(t)=(0,0,\dots,0)$ is the equilibrium point.

Find the linearization equation of differential equation (4) at $E_i^*(t)$, and the partial derivative matrix is:

$$DF=\begin{bmatrix}\frac{\partial f_1}{\partial E_1} & \frac{\partial f_1}{\partial E_2} & \cdots & \frac{\partial f_1}{\partial E_n}\\ \frac{\partial f_2}{\partial E_1} & \frac{\partial f_2}{\partial E_1} & \cdots & \frac{\partial f_2}{\partial E_n}\\ \cdots & \cdots & \cdots & \cdots\\ \frac{\partial f_n}{\partial E_1} & \frac{\partial f_n}{\partial E_2} & \cdots & \frac{\partial f_n}{\partial E_n}\end{bmatrix} \tag{5}$$

Where, $\frac{\partial f_i}{\partial E_i}=\alpha_i+\delta_i(E_1,E_2,\dots,E_n)+E_i\frac{\partial\delta(E_1,E_2,\dots,E_n)}{\partial E_i}$, $\frac{\partial f_i}{\partial E_j}=E_i\frac{\partial\delta(E_1,E_2,\dots,E_n)}{\partial E_j}$, $i\neq j$.

Combining $\delta_i(0,0,\dots,0)=0$, at equilibrium point $E^*=(0,0,\dots,0)$, the partial derivative matrix is:

$$DF(E^*) = \begin{bmatrix} \alpha_1 & 0 & \dots & 0 \\ 0 & \alpha_2 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & \alpha_n \end{bmatrix} \tag{6}$$

The linearization equation $(\dot{E}_1, \dot{E}_2, ..., \dot{E}_n)^T = DF(E^*)(E_1, E_2, ..., E_n)^T$ corresponding to the origin of formula (4) can be obtained, that is

$$\dot{E}_i = \alpha_i E_1 \tag{7}$$

Where, formula (7) coefficient matrix $DF(E^*)$ features $\lambda_i = \alpha_i \neq 0$. Due to the weakening of nonlinearity near the equilibrium point, it is necessary to use formula (7) to determine whether formula (5) is stable at the origin.

Based on the Lyapunov stability criterion, when $\alpha_i < 0$, $E_i(t)$ is a slow variable; The large damping coefficient is a fast variable, maintaining the stability of formula (4) at the origin. When $\alpha_i > 0$, $E_i(t)$ is a slow variable and an unstable variable, while other variables are fast variables, formula (4) is unstable. It is worth noting that at this point, the model is dominated by slow variables, which are transformed into order parameters.

According to the above method, variables are divided into two groups: fast variables and slow variables. In this article, slow variables and fast variables are respectively recorded as $E_l(t), h = 1, 2, ...h$; $E_s(t), h = h + 1, h + 2, ...n$.

Due to the uncorrelation between variables, $\delta_i(E_1, E_2, ..., E_n) = 0$, its impact on the rate of change of the dependent variable can be recorded as the function of E_j on the rate of change of E_i, $\delta_{ij}(E_j)$. It can be inferred that:

$$\delta_i(E_1, E_2, ..., E_n) = \sum_{j=1}^{n} \delta_{ij}(E_j) \tag{8}$$

According to the principle of synergetics, when fast variables are represented by slow variables, the order parameter equation can be derived by adiabatic approximation of $\dot{E}_s(t), h = h + 1, h + 2, ...n$:

$$E_s(t) = -\delta_{ss}^{-1}\left(\alpha_s + \sum_{j=1, j\neq s}^{n} \delta_{sj}(E_j(t))\right) \tag{9}$$

The simultaneous fast variable depends on the solution of the slow variable:

$$E_s(t) = E_s(E_1(t), E_2(t), ..., E_h(t)) = E_s(E_l(t)) \tag{10}$$

Thus, the order parameter equation can be obtained:

$$\dot{E}_l = \alpha_l E_l + \delta_l(E_l, E_s(E_l))E_l \tag{11}$$

Combining the actual situation of RMID with the order parameter model, the specific steps are as follows.

Step 1: Mathematize the problem. E_1 is the internal cause of a subsystem. E_2 is controlled by the internal cause. The motion equation is as follows:

$$\dot{E}_1 = \beta_1 E_1 + aE_1E_2 + bE_1^2 \tag{12}$$

$$\dot{E}_2 = \beta_2 E_2 + cE_1E_2 + dE_2^2 \tag{13}$$

where, E_1, E_2 are the state variables. a, b, c, d, β_1 and, β_2 are the control variables, β_1 and β_2 represent the damping coefficient of the two subsystems, respectively, and a, b, c, and d reflect the interaction strength of E_1 and E_2. When the system reaches a steady-state solution, i.e., $E_1 = E_2 = 0$, $|\beta_2| \gg |\beta_1|$, and $\beta_2 > 0$, this indicates that the state variable β_2 of the system is a fast variable that decays rapidly. This realization process is called the “adiabatic approximation hypothesis” of the motion system. In practice, the difference between β_1 and β_2 is required to be at least one order of magnitude.

Step 2: Eliminate fast variables. If the “adiabatic approximation hypothesis” holds, let $\dot{E}_2 = 0$. Then, the $E_2 = -\frac{(\beta_2 + cE_1)}{d}$ can obtained. We can obtain the evolution equation as follows:

$$\dot{E}_1 = \frac{d\beta_1 - a\beta_2}{d}E_1 + \frac{bd - ac}{d}E_1^2 \tag{14}$$

where, E_1 determines E_2, and E_2 changes with the change of E_1.

Then, in the system, it is a general rule that the body will produce different potential energy due to the displacement of the system, and the potential energy is reflected in external work. Therefore, it can effectively judge whether the system is in a relatively stable state by constructing and solving the potential function. According to the equation of motion and the order parameter of the system, Haken solved the potential function and judged the state of the system.

Step 3: The order parameter equation is obtained. The potential function can be obtained by integrating $\dot{E}_1$ in the opposite number. formula (4).

$$v = \frac{1}{2}\beta_1 E_1{}^2 + \frac{cd}{4\beta_2} E_1{}^4 \tag{15}$$

4. Experiment and analysis

4.1. Data Sample and source

After nearly 40 years, GD has become an important manufacturing production base in China. At the same time, it has initially formed a manufacturing industry system with distinctive industrial characteristics and large-scale, high-level, and obvious agglomeration development trends. Therefore, this study mainly focused on RMID in the 21 cities in GD. These cities are listed in Table 1. The data is sourced from official statistics of the Guangdong Provincial Government in China (http://stats.gd.gov. cn/gdtjnj/).

4.2. Data detection

By testing the correlation coefficients of each variable, it was observed from Table 2 that technology and environment have a positive correlation with RMID. However, their correlation is not high, indicating a high degree of independence between the variables. In addition, from Table 3, the variance inflation factor (VIF) test for all variables was below the threshold of 10, and there was no multicollinearity among the variables. This is more in line with the input of the order parameter model.

4.3. Results and analysis

This paper constructs industrial environmental systems and industrial technology systems. According to formulas (1) and (2), the differential equations are constructed as follows:

$$\dot{E}_{1,city} = \sum_{city=1}^{n} \beta_{1,city} E_{1,city} + a_{city} E_{1,city} E_{2,city} + b_{city} E_{1,city}^2 \tag{16}$$

$$\dot{E}_{2,city} = \sum_{city=1}^{n} \beta_{2,city} E_{2,city} + c_{city} E_{1,city} E_{2,city} + d_{city} E_{2,city}^2 \tag{17}$$

$$\dot{E}_{3,city} = \sum_{city=1}^{n} \beta_{3,city} E_{3,city} + f_{city} E_{3,city} E_{4,city} + g_{city} E_{3,city}^2 \tag{18}$$

$$\dot{E}_{4,city} = \sum_{city=1}^{n} \beta_{4,city} E_{4,city} + h_{city} E_{3,city} E_{4,city} + k_{city} E_{4,city}^2 \tag{19}$$

The linear term coefficients $\beta_{1,city}$, $\beta_{2,city}$, $\beta_{3,city}$, and $\beta_{4,city}$ represent the growth rate of the variable itself. The cross-term coefficients a_{city}, c_{city}, f_{city}, and h_{city} indicate the interaction between linear terms. The terms b_{city}, d_{city}, g_{city}, and k_{city} indicate the influence degree caused by the change of the variable itself.

As shown in Tables 4 and 5, the parameters vary between different cities, and specific parameter explanations can be found in Section 3.2. As can be seen from this article, (1) the development level of RMID varies among different cities in the industrial environment system. Therefore, the existing manufacturing industry in some cities will increase and hinder their development. Almost all urban environmental variables will have a growth effect on themselves. (2) Similarly, with the passing of time all of these variables hinder the development of the existing environment. In the industrial technology system, the existing RMID in some cities will also

Table 1
Research subjects.

Abbreviation	City	Abbreviation	City	Abbreviation	City
GZ	Guangzhou	SZ	Shenzhen	ZH	Zhuhai
ST	Shantou	FS	Foshan	SG	Shaoguan
HY	Heyuan	MZ	Meizhou	HZ	Huizhou
SW	Shanwei	DG	Dongguan	ZS	Zhongshan
JM	Jiangmen	YJ	Yangjiang	ZJ	Zhanjiang
MM	Maoming	ZQ	Zhaoqing	QY	Qingyuan
CZ	Chaozhou	JY	Jieyang	YF	Yunfu

Table 2
The correlation test.

	RMID	technology	environment
RMID	1		
technology	0.1688	1	
environment	0.4805	0.4955	1

Table 3
VIF test.

	VIF	1/VIF
technology	1.33	0.7545
environment	1.33	0.7545

Table 4
The order parameter coefficient symbols.

	$\beta_{1,city}$	a_{city}	b_{city}	$\beta_{2,city}$	c_{city}	d_{city}	$\beta_{3,city}$	f_{city}	g_{city}	$\beta_{4,city}$	h_{city}	k_{city}
GZ	−	+	−	+	−	−	−	+	+	−	+	+
SZ	−	+	−	+	−	−	−	+	−	+	+	−
ZH	+	−	−	+	−	−	+	−	−	+	−	−
ST	+	−	−	+	−	−	+	−	+	−	+	+
FS	+	−	−	+	−	−	+	−	−	−	−	+
SG	−	−	+	−	+	−	−	+	+	−	+	−
HY	−	+	−	+	−	−	−	+	+	+	−	+
MZ	+	−	−	+	−	−	+	+	−	−	−	+
HZ	+	−	−	+	+	−	+	−	−	+	−	−
SW	−	−	+	+	+	−	+	−	+	−	−	+
DG	+	+	−	+	+	−	+	+	−	−	+	+
ZS	+	−	−	+	+	−	+	−	−	+	+	−
JM	+	−	−	+	+	−	+	−	−	−	+	+
YJ	−	+	−	+	+	−	+	−	+	−	+	+
ZJ	−	+	−	+	+	−	+	−	−	+	−	+
MM	−	+	+	+	−	−	+	−	+	−	+	+
ZQ	+	−	+	+	+	−	+	−	−	−	+	−
QY	+	+	−	+	−	−	+	+	−	−	+	+
CZ	+	−	+	+	+	−	−	+	+	−	+	+
JY	−	+	+	+	−	−	+	−	−	+	−	+
YF	+	−	+	+	+	−	−	+	+	−	−	+

Note: + indicates a positive coefficient, − indicates a negative coefficient.

increase and hinder their development. Although not all cities' technological variables will have an increasing effect on their own development, with the passing of time, most cities will have an increasing effect on the existing technological development. The effects of environment and technology on RMID are different, which need to be further analyzed by order parameters.

Secondly, according to the adiabatic approximation principle, if $E_{2,city} \neq 0$, we let $\dot{E}_{2,city} = 0$ and express the fast variable from the slow variable $E_{1,city}$, as $E_{2,city} = \sum_{city=1}^{n} - \left(\beta_{2,city} + c_{city}E_{1,city}\right)/d_{city}$. After substituting it into formula (16), the order parameter equation conforming to the evolution process of logistics is obtained:

$$\dot{E}_{1,city} = \sum_{city=1}^{n} \frac{d_{city}\beta_{1,city} - a_{city}\beta_{2,city}}{d_{city}} E_{1,city} + \frac{b_{city}d_{city} - a_{city}c_{city}}{d_{city}} E_{1,city}^{2} \tag{20}$$

By introducing the function $v(E_1)_{1,city}$, the formula of industrial environmental system can be derived when formula (3) is satisfied. The formula is as follows:

$$v_{1,city} = \sum_{city=1}^{n} \frac{d_{city}\beta_{1,city} - a_{city}\beta_{2,city}}{2d_{city}} E_{1,city}^{2} + \frac{b_{city}d_{city} - a_{city}c_{city}}{3d_{city}} E_{1,city}^{3} \tag{21}$$

Similarly, the formula of industrial technology system can be deduced:

$$v_{2,city} = \sum_{city=1}^{n} \frac{k_{city}\beta_{3,city} - f_{city}\beta_{4,city}}{2k_{city}} E_{1,city}^{2} + \frac{g_{city}k_{city} - f_{city}h_{city}}{3k_{city}} E_{1,city}^{3} \tag{22}$$

Through the simulation of potential functions $v_{1,city}$ and $v_{2,city}$, the motion trajectories of virtual particles of $E_{1,city}$ and $E_{2,city}$ can be

Table 5
The order parameter coefficient values.

	$\beta_{1,city}$	a_{city}	b_{city}	$\beta_{2,city}$	c_{city}	d_{city}	$\beta_{3,city}$	f_{city}	g_{city}	$\beta_{4,city}$	h_{city}	k_{city}
GZ	−0.05	0.00	−0.11	1.11	−0.27	−0.17	−1.01	42.84	1.70	−0.46	1.11	20.29
SZ	−0.01	0.01	−0.18	1.11	−0.87	−0.11	−0.02	1.14	−0.11	0.17	0.25	−8.02
ZH	0.87	−0.11	−0.73	0.64	−0.43	−0.08	1.60	−27.06	−3.13	0.41	−0.36	−11.47
ST	0.92	−0.16	−0.22	0.66	−0.14	−0.11	0.00	−10.60	0.06	−0.33	0.38	11.66
FS	0.68	−0.07	−0.61	2.31	−0.95	−0.32	0.28	−9.11	−0.39	−0.43	−1.01	95.08
SG	−0.13	−0.06	0.51	−0.41	4.86	−1.00	−0.18	6.99	0.21	−0.14	0.73	−9.85
HY	−0.34	0.10	−0.22	1.45	−0.65	−0.30	−0.27	98.43	0.08	0.21	−2.27	14.02
MZ	0.47	−0.02	−2.10	2.74	−10.09	−0.21	0.29	41.69	−2.25	−0.48	−0.44	23.32
HZ	0.26	−0.03	−0.16	0.57	0.09	−0.10	1.00	−36.11	−1.41	0.45	−0.51	−8.77
SW	−0.01	−0.09	1.38	1.09	5.90	−0.58	0.29	−81.56	0.00	−0.97	−1.00	58.06
DG	0.29	0.11	−2.07	0.27	0.38	−0.07	0.55	15.81	−1.63	−0.87	1.80	19.63
ZS	0.88	−0.13	−0.30	1.09	0.10	−0.19	0.29	−6.39	−0.59	0.06	1.37	−62.89
JM	1.05	−0.06	−2.01	1.02	0.00	−0.22	1.85	−46.88	−3.57	−1.20	2.31	38.19
YJ	−0.24	0.07	−0.15	0.26	0.49	−0.13	0.66	−184.78	0.26	−1.22	1.07	35.97
ZJ	−0.07	0.09	−1.27	0.02	0.68	−0.06	0.03	−22.05	−0.02	0.43	−3.40	19.45
MM	−0.08	0.00	0.05	1.33	−0.70	−0.22	0.21	−83.37	0.64	−0.73	0.03	40.57
ZQ	0.97	−0.23	0.30	1.17	0.41	−0.27	1.38	−129.89	−1.53	−0.26	2.09	−33.81
QY	0.65	0.04	−2.69	3.73	−5.07	−0.52	0.66	21.46	−2.52	−0.40	0.14	19.64
CZ	1.12	−0.28	0.80	0.53	0.05	−0.10	−0.52	94.55	0.15	−0.33	0.14	11.31
JY	−0.78	0.10	0.30	1.68	−0.32	−0.27	0.20	−45.34	−0.22	0.23	−1.12	14.27
YF	0.00	−0.20	1.87	0.11	5.83	−0.55	−1.21	239.00	1.08	−0.52	−1.61	35.04

obtained, respectively (see Fig. 1 (a - u) and 2 (a - u)).

As shown in Fig. 1 (a - u) and 2 (a - u), the overall growth rates of potential function parameters gradually change over time. In other words, Fig. 1 (a - u) shows that the RMID trends affected by the environment vary among different cities. The curve in each graph represents the degree of change affected, which can be roughly divided into upward, downward, and slowing development. Among them, two-thirds of cities adopt green development to promote industrial growth, while the development of other cities slows down (3/21), and some cities have a slight downward trend (4/21). Fig. 2 (a - u) shows that RMIDs in different cities have varying trends influenced by technology. The curve in each graph represents the degree of change affected, which can be roughly divided into rising, falling, slowing, and regressing development. Among them, half of the cities promote industrial growth, but there are still three other situations: development slow down (3/21), a slight downward trend (5/21), and recession (2/21). Specifically, as follows.

(1) For environmental development, there are three main situations, which are described as follows:

Case 1. the growth rate of order parameters increases gradually with time. The environment has a positive incentive effect on RMID. These cities should pay attention to green development, but the strengthening of industrial-pollution prevention and protection of the environment is an important position. In this way, industrial growth can be based on sustainable development. In other words, their continuous improvement of pollution control has promoted RMID into a period of rapid development.

Case 2. the growth rate of order parameters gradually declines with time. With the improvement of RMID, the blocking effect of pollution will gradually become prominent. It has a crowding-out effect on RMID. Environmental problems have become the bottleneck restricting RMID. In other words, the RMID of these cities will gradually fall into difficulties with the hindrance, and the balance needs to be broken through new order parameters. Therefore, in the middle and later stages of manufacturing development, the government should pay attention to green development, to ensure that RMID enters a new round of development.

Case 3. the growth rate of order parameters gradually slows down with the passing of time. It starts to rise after reaching a certain degree, but there is a downward trend in the future. That is, the RMID of the environment in these cities showed a “U” shape in the initial stage, but then showed a downward trend. This shows that with the increase of environmental regulation intensity, RMID is inhibited at first and then promoted. However, the dilemma faced by RMID in these cities has not been relieved. With continuous development, there is still a downward fluctuation trend in the future.

(2) For technological development, there are four situations, which are described as follows:

Case 1. the growth rate of order parameters increases gradually with time. These cities focus on technological research and development, highlighting technological innovation and scientific and technological progress. By attaching importance to the advanced and applicable technologies, the government can accelerate RMID. Namely, with continuous innovation, RMID can enter a period of rapid development.

Case 2. the growth rate of order parameters gradually slowed down with time and then began to weaken. Technology R&D in these

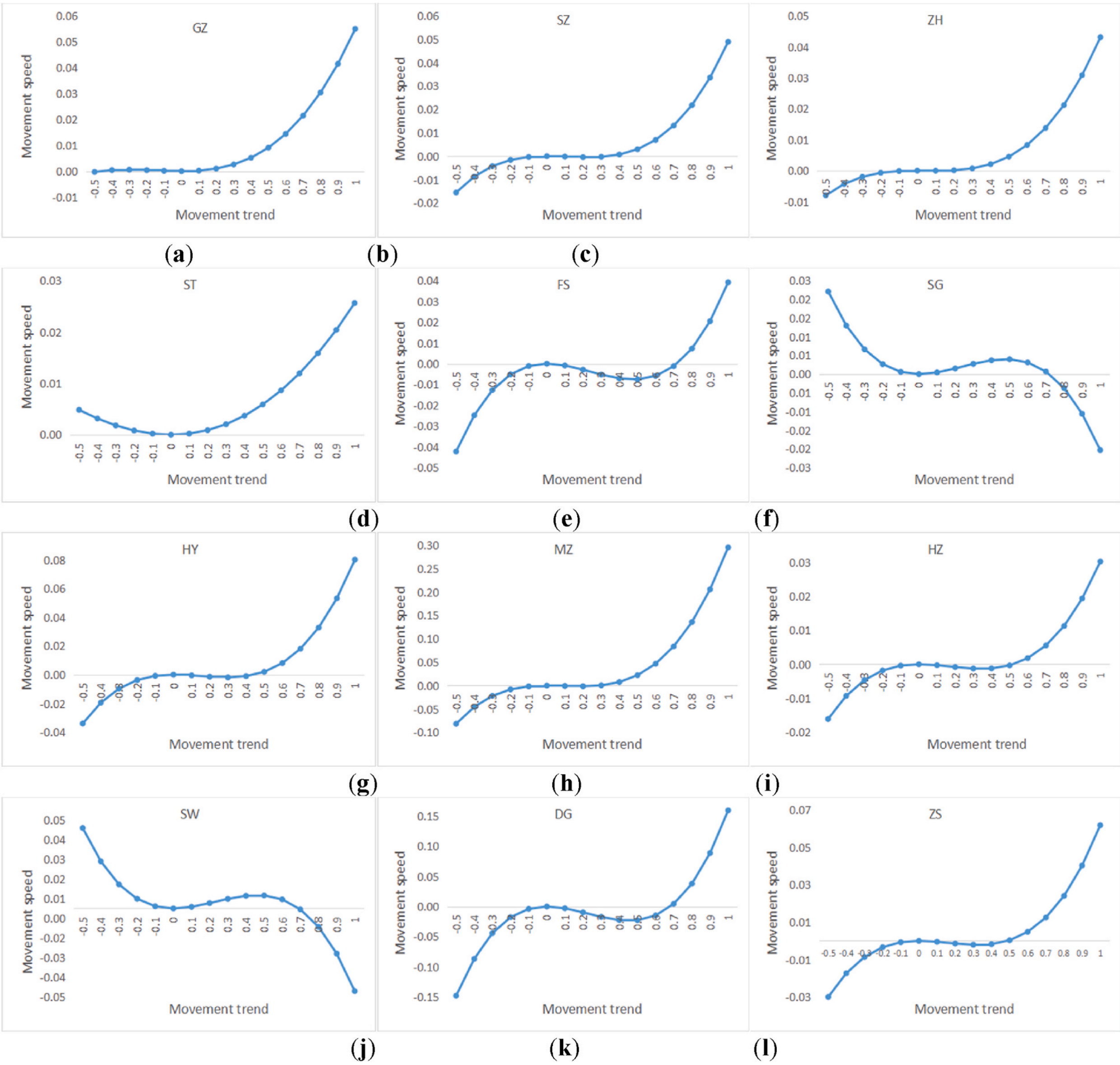

Fig. 1. (a–u). Potential function simulation diagrams of industrial environmental systems in different cities. (a) GZ, (b) SZ, (c) ZH, (d) ST, (e) FS, (f) SG, (g) HY, (h) MZ, (i) HZ, (j) SW, (k) DG, (l) ZS, (m) JM, (n) YJ, (o) ZJ, (p) MM, (q) ZQ, (r) QY, (s) CZ, (t) JY, and (u) YF.

cities may encounter bottlenecks, which may hinder industrial development. At this time, the technical dilemma has become the bottleneck of RMID. That is, these cities need to find new technologies to break the difficulties described above, meaning technological diversification.

Case 3. the growth rate of order parameters gradually slows down with time. It starts to rise after reaching a certain level, but there is a downward trend in the future. That is, the change in technology R&D shows a “U” shape for the initial stage of RMID in these cities, but then there is a downward trend. This shows that these cities face difficulties in the early stages of technology research and development. However, this is improved through the diversified development of technology. Therefore, this reflects the role of inhibiting industrial development at first and then promoting it. However, the dilemma of technology R&D in these cities has not been completely solved, and there is still a downward fluctuation trend in the future.

Case 4. the decline rate of the order parameter gradually slows down with time, but then the decline rate gradually increases. That is the lack of technology research and development results in an inverted “U” shape of RMID for these cities. Therefore, these cities urgently need to improve the R&D of industrial technology. Otherwise, with the development of time, its technical level will seriously

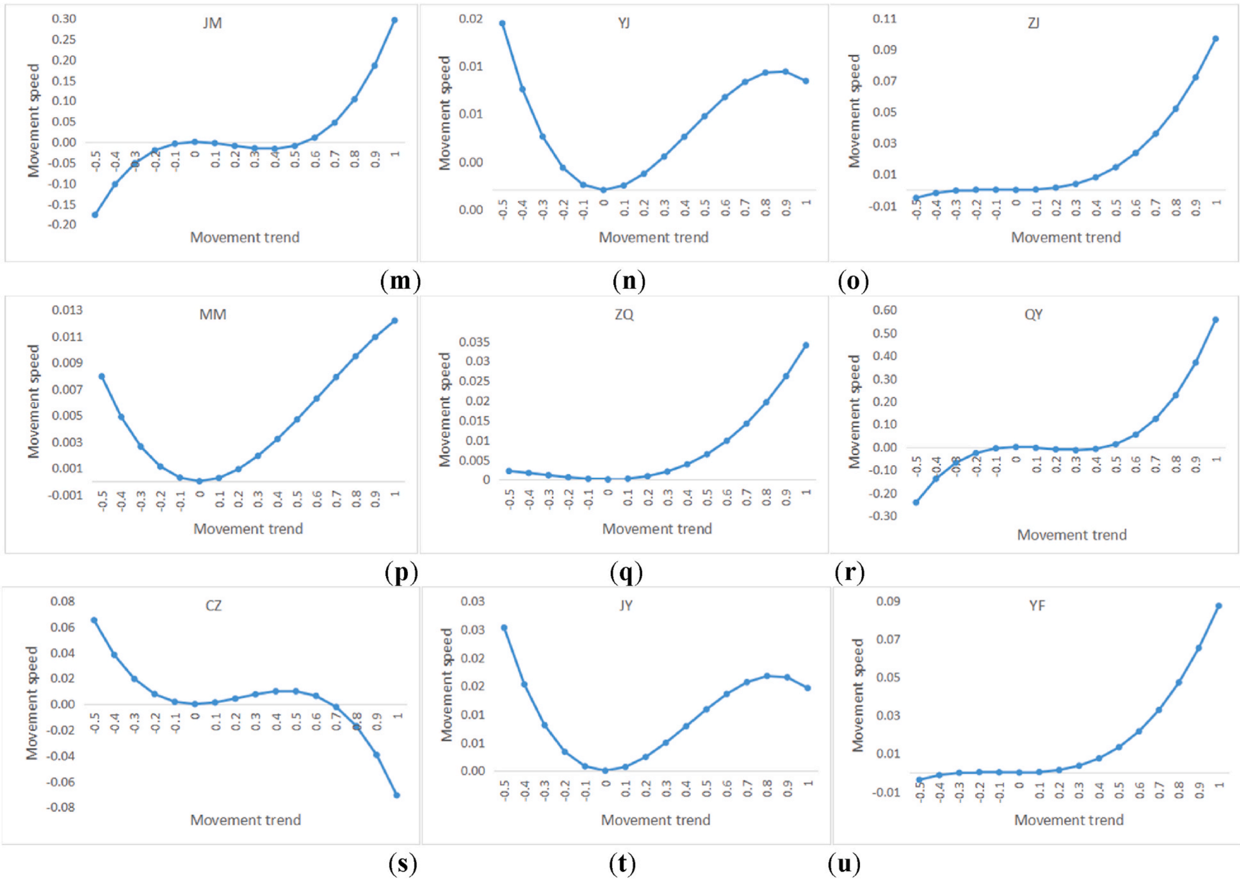

Fig. 1. (*continued*).

limit RMID and cause the retreat of RMID.

The industrial environment and industrial technology development trajectories of 21 cities in GD are slightly different. To more intuitively reflect them, we visualize and classify them (see Figs. 3 and 4). Specifically, two-thirds of cities adopt environment development to promote industrial growth. On the other hand, only half of the cities adopt new technologies to promote industrial growth.

According to NSE theory, it can be explained that RMID has different concerns at different times. That is, technology and green development belong to tasks at different stages. Based on this, the theory can be used to study the determinants and impact stages of its changes.

Although this environment and technology will ultimately affect RMID, their impact trends are slightly different. On this basis, the impact of different factors on RMID was studied from the perspective of NSE. The determining factors and impacts of RMID vary over time, as shown in Fig. 5.

Based on the results of order parameters, 21 cities were classified into technology-green development categories, as shown in Fig. 5, which displays the degree of impact between technology and green. Specifically, the impact of technology and environment on RMID is matched in most cities, and green development improves with the development of technology. However, some cities have poor technological development, but the impact of green development on RMID is significantly higher. Therefore, this article proposes technological development paths for different cities. Then, based on technological development, providing corresponding green development plans.

Firstly, propose a technological development path for RMID based on the results of order parameters. In terms of technological development, the government should consider the differentiation of regional industrial development. According to the development of the region, formulate relevant policies for technological development according to local conditions, to promote sustainable RMID.

(1) The regional technology of the industrial technology system case 1 is relatively developed, which brings positive incentives to the manufacturing industry. Therefore, the local government needs to formulate laws to protect the rights and interests of enterprises' technological achievements and avoid risk behaviors in the process of technological-product trading.
(2) For regions with industrial technology case 2, the quality of technology development should be further improved to solve the development dilemma. The local government should encourage enterprises to cultivate their own brands. Enterprises should

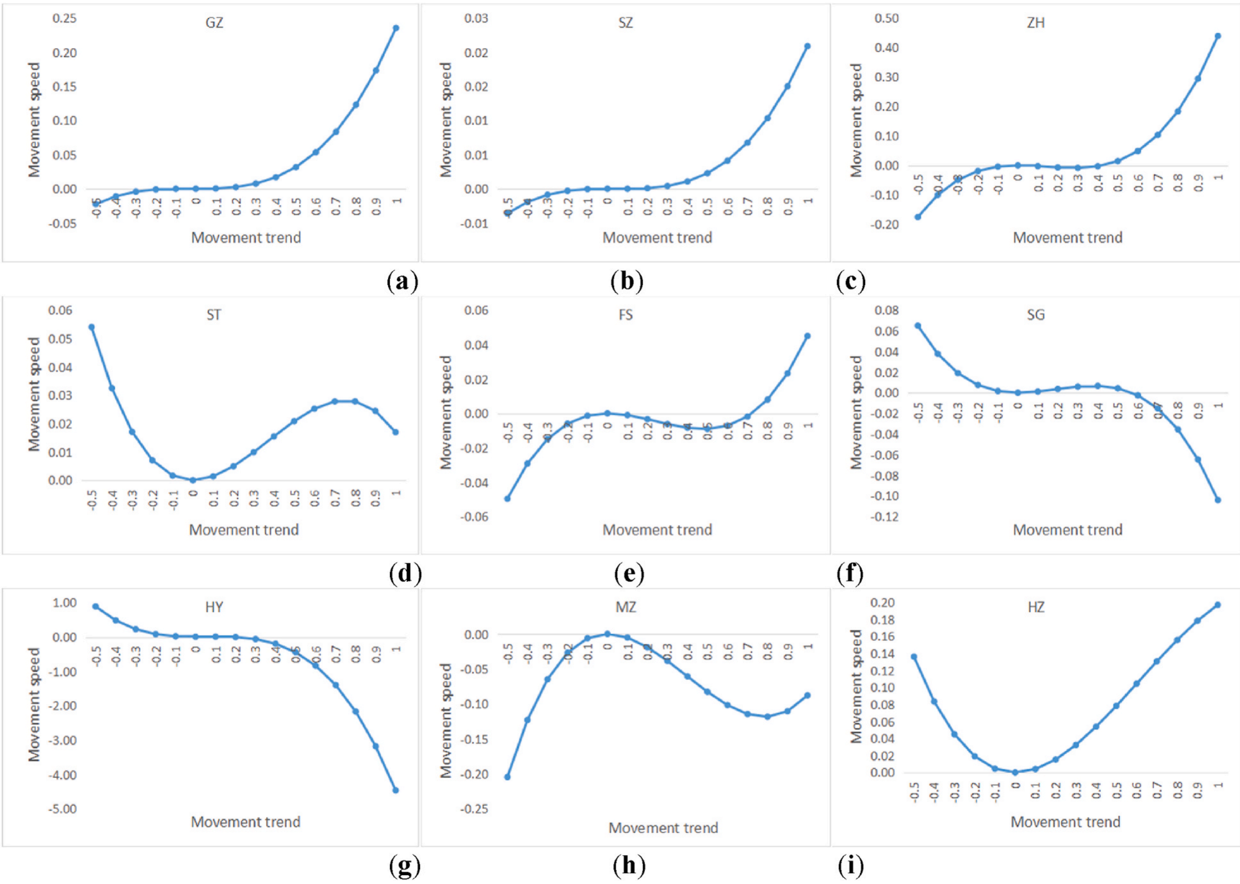

Fig. 2. (a–u). Potential function simulation diagrams of industrial technology systems in different cities. (a) GZ, (b) SZ, (c) ZH, (d) ST, (e) FS, (f) SG, (g) HY, (h) MZ, (i) HZ, (j) SW, (k) DG, (l) ZS, (m) JM, (n) YJ, (o) ZJ, (p) MM, (q) ZQ, (r) QY, (s) CZ, (t) JY, and (u) YF.

improve their R&D ability and technological innovation ability, optimize the research of key technologies, and actively design products with independent intellectual property rights.

(3) For regions with industrial technology case 3, the government should pay attention to the overall manufacturing supply chain matching. It should establish and provide complete system design standards, specifications, database, and supporting services of the development platform to ensure sustainable RMID.

(4) For regions with industrial technology case 4, the scientific and technological innovation ability of the region can be improved by introducing scientific and technological talents and encouraging enterprise R&D investment. In addition, education expenditure should be strengthened to provide human capital for technological innovation.

Based on technological development, we propose environmental development paths for RMIDs in different groups according to Fig. 5.

(1) Cities showing strong technological impact on RMID, including GZ and the other ten cities, should continue to maintain a green development trend. Due to the long-term development of RMID's green transformation, the government should maintain its efforts in environmental regulation. Meanwhile, considering the technological advantages of such cities, the local government should develop green and clean high-tech industries, encourage them to innovate in green technology, and promote high-quality sustainable RMID.

(2) There are three situations in cities where technology has a moderate impact on RMID. According to the degree of environmental development, it is arranged as HZ > ST, YJ, MM > SW. Local governments should implement supporting incentive policies for environmental regulation, encouraging the aforementioned cities to solve current environmental problems by introducing green technologies and absorbing and improving existing green technologies. Among them, HZ has a good environment, indicating that the city attaches great importance to green development. In the future, efforts should be made to transform green technologies into economic benefits, such as improving green products. ST, YJ, and MM have moderate environments and need to further enhance their green transformation. They should improve their green level in the production process by introducing

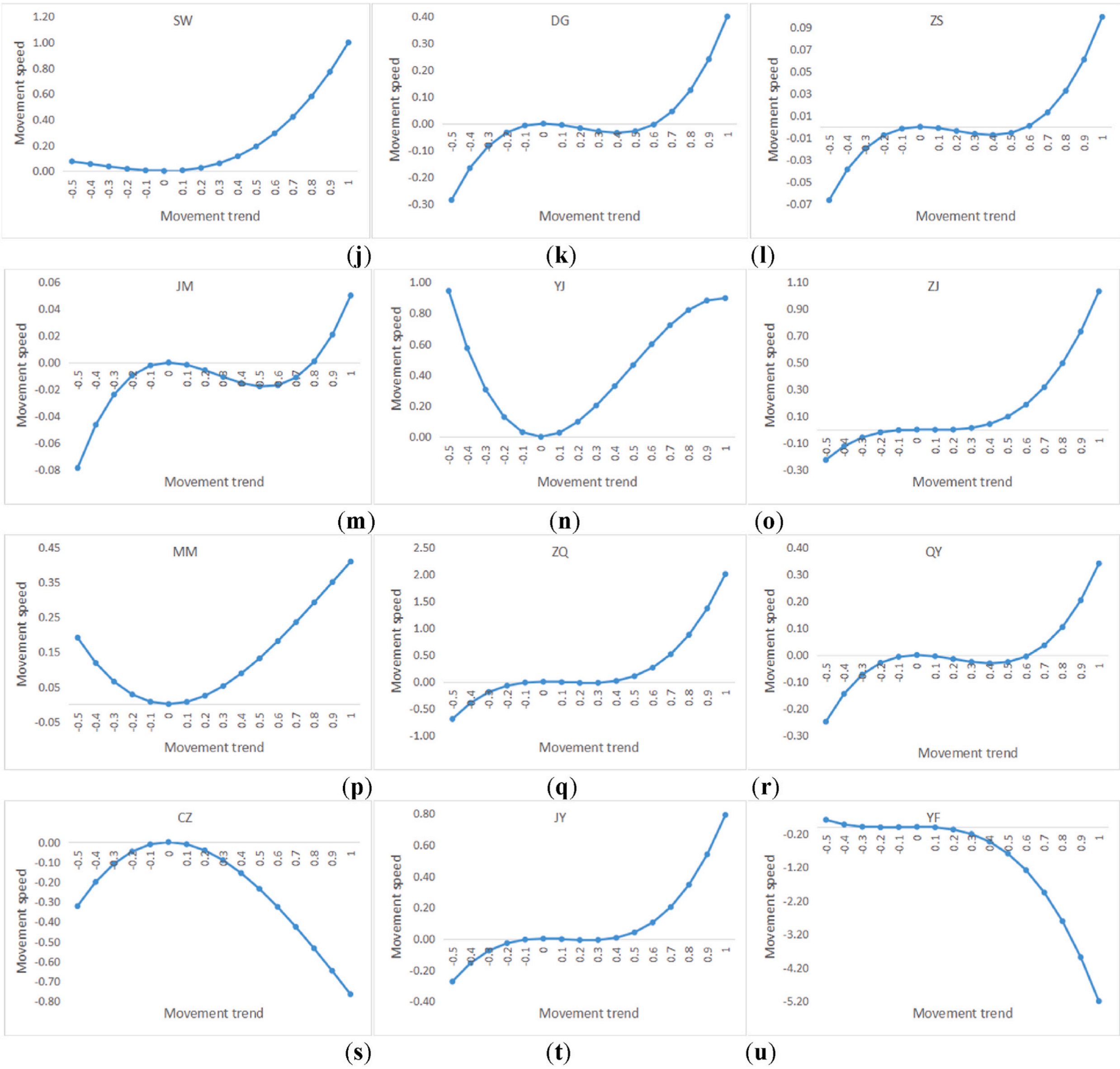

Fig. 2. (*continued*).

green production lines. The SW environment is weak, and attention should be paid to solving pollution problems. It should introduce end-of-life pollution control technology. Based on this plan, these cities can achieve RMID sustainability.

(3) Cities with a weaker technological impact on RMID face technological difficulties. However, there are two extreme situations where the environment has an impact on RMID. The first situation is that the environment has a weak impact on these cities, such as SG and CZ. These local governments should strengthen the promotion of environmental policies and encourage the development of green technologies. In addition, green technology should be purchased and introduced to curb polluting enterprises and address pollution issues from the source. This can quickly improve the current environmental pollution problem and achieve the economic goal of green development. The second situation is that the environment has a strong impact on cities, such as HY, MZ, and YF. This type of local government should summarize the experience of green development and carry out structural transformation without affecting the current environment. On this basis, by gradually introducing green technologies, they can maintain the green development of local industries.

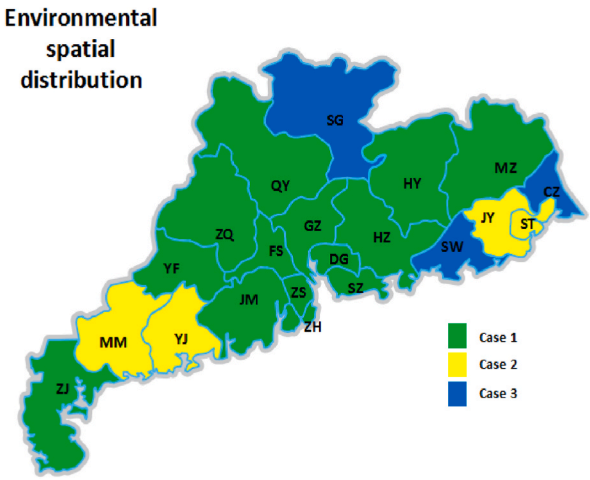

Fig. 3. Environmental development of the 21 cities.

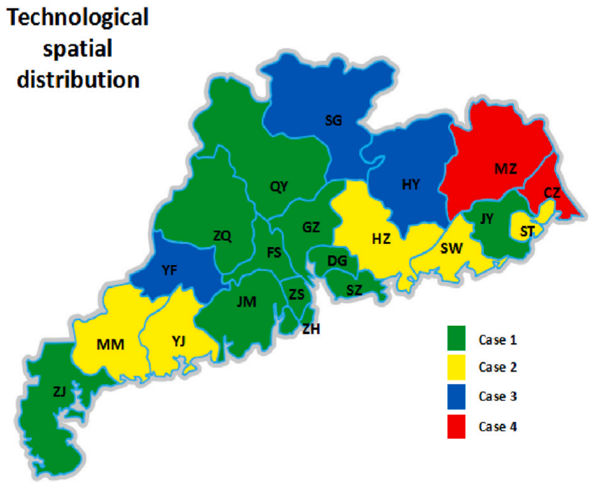

Fig. 4. Technological development of the 21 cities.

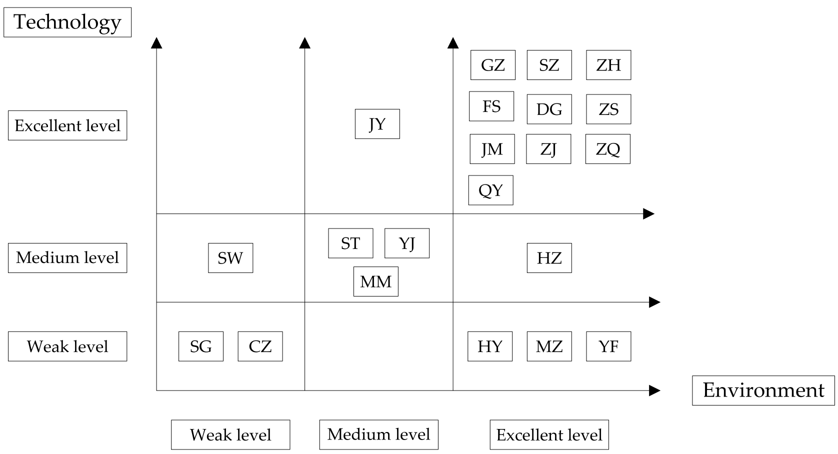

Fig. 5. Technical- and environmental-impact degrees of RMID in 21 cities.

5. Discussion

5.1. Main findings

(1) Relationship between environment and RMID

Traditional manufacturing industries can cause great damage to and consumption of the environment and resources, making it important to pay attention to ecological environment protection during their development. In other words, the ecological environment cannot be harmed by improving economic benefits. As a result, some scholars have conducted relevant research. For example, Wu et al. [29] believe that controlling environmental pollution is the key to affecting manufacturing development. Sun et al. [33] and Shen et al. [34] found that the manufacturing industry in a province is significantly affected by environmental factors. Sheng et al. [35] found that the purpose of environmental regulations is not to relocate polluting industries, but to encourage enterprises to improve the quality of their products, thereby increasing their productivity. Zhu et al. [37] studied the carbon-reduction effects of green-technology-innovation subsidies and carbon-emission trading on manufacturing enterprises. When manufacturing focuses on reducing its impact on the environment, it will achieve the greatest social benefits. An et al. [39] found that environmental regulations can promote manufacturing agglomeration. However, as the prediction period prolongs, the promoting effect transforms into an inhibitory effect. The above literature provides reference for this study.

In fact, this article found three different situations. Firstly, the environment has a positive motivating effect on RMID. Due to the city's emphasis on green development, RMID has entered a period of rapid development. Secondly, environmental issues have become a bottleneck restricting RMID. With severe urban pollution, its blocking effect will gradually become prominent. At this point, RMID will gradually fall into a development dilemma. Thirdly, there is a non-linear impact between the environment and RMID. This indicates that as the intensity of environmental regulation increases, RMID is first suppressed and then promoted. However, there is still a downward trend of fluctuations in the future.

(2) Relationship between technology and RMID

The overall competitiveness of the manufacturing industry cannot be improved without technological innovation. Innovation-driven manufacturing can solidly promote the rational transformation of industrial structure. As a result, some scholars have conducted relevant research. For example, Wang et al. [9] found that AI technology can improve the total factor productivity (TFP) of manufacturing enterprises. Dou et al. [42] studied the impact of technological development on manufacturing demand. They found that technology can improve production efficiency. Ronaghi [45] discovered that artificial intelligence technology can change manufacturing processes. Huang et al. [46] found that the impact of intelligent development on the TFP of manufacturing enterprises is generally positive. Sarbu [47] studied the impact of Industry 4.0 on the innovation of manufacturing enterprises. It found that new technologies can promote product innovation in enterprises. Kim et al. [48] found that adopting front-end technology can have an impact on the existing business growth of manufacturing enterprises. When enterprises develop new businesses, adopting basic technologies will have a positive impact on their growth. The above literature provides reference for this study.

In fact, this article found four different situations. Firstly, technology has a positive motivating effect on RMID. Through continuous innovation, RMID can enter a period of rapid development. Secondly, technological challenges have become a bottleneck for RMID. Technological development has encountered bottlenecks and is in a stagnant stage. At this point, RMID is suppressed. Thirdly, technological development and RMID changes are in a "U" shape. This indicates that technology has a first inhibitory and then promoting effect on RMID, but the technological research and development difficulties in these cities have not been fully resolved. Fourthly, technological development and RMID changes exhibit an inverted "U" shape. Over time, its technological level will severely limit RMID and lead to its decline.

5.2. Theoretical contribution

Previous studies have confirmed the impact of environment and technology on industry. The environmental regulation can improve productivity [36], reduce pollution [62], improve competitiveness [63], and bring economic benefits to the manufacturing industry [29]. The technological innovation has positive impact on the manufacturing industry, such as improving productivity [10], promoting product innovation [47], and expanding business [44]. However, few studies have compared the two and explored the differences in their impact on RMID. Our research results compared the impact of environmental and technological developments on RMID. Specifically, two thirds of cities adopt environmental development to promote industrial growth. In addition, only half of the cities have adopted new technologies to promote industrial growth. Through comparison, it can be found that the environment has a greater promoting effect on RMID.

Regarding such issues, most use the economic regression method [30,63] and evaluation systems method [19]. However, due to different methods, there are some differences in the results. Specifically, the econometric regression can confirm the coefficient and significance of a variable's impact on RMID, but it cannot characterize the dynamic trend or rate of change of the variable on RMID. The evaluation system can characterize the score of RMID at a certain time section and compare it with different cities, but it is also unable to characterize its dynamic trend. At this point, the advantages of the order parameter method can be observed. The order parameter method can not only calculate the trend of changes in various variables, including promotion, inhibition, and event reception. For example, Li et al. [64] simplified and mathematically processed the system parameters, proposed the adiabatic approximation principle to identify influencing factors, judged whether the various parameters of the motion equation could meet the assumption of the adiabatic approximation principle, and identified the key driving factors of system evolution. Choosing an order parameter model can effectively identify the patterns of changes between industries. Numerous studies have confirmed this. Jin et al. [65] used the sequential parameter method to study the characteristics of industry structure and corporate behavior. Using this method, it is also possible to calculate the rate of change of variables on the research subject. It can effectively identify the trends and differences in the impact of environmental and technological variables on RMID in different cities.

In addition, existing theories (PEST [50], SWOT [52], and Diamond theories [57]) focus on the factors that initially affect the industry in the short term, while ignoring the factors that promote or hinder sustainable RMID. To fill this research gap, we used NSE theory to analyze the influencing factors of RMID. According to the NSE theory, it can be explained that RMID has different focuses at different times. That is to say, technology and green development belong to different stages of tasks. This can reasonably explain the differential effects of different variables on RMID from a theoretical perspective.

5.3. Suggestion

In the context of economic uncertainty [66,67], RMID faces severe challenges. To ensure the sustainable development and increase output value of RMID, the government needs to take a series of targeted measures to optimize RMID from both environmental and technological aspects.

The specific policy guidance in terms of environment is as follows: (1) The government should introduce stricter environmental protection laws and regulations, put forward clear requirements for emission standards and force enterprises to reduce pollution and improve resource utilization efficiency. (2) The government should develop green credit and green bond markets, provide low-cost green financing channels for enterprises, and support their investment and innovation in the field of environmental protection. (3) The government encourages enterprises to carry out green technology transformation through tax incentives, financial subsidies, and other means, such as updating energy-saving equipment and applying clean production processes. (4) The government should increase its efforts to investigate and punish illegal discharge of pollutants, ensuring that all enterprises comply with environmental regulations. At the same time, the government provides technical support and guidance to help enterprises meet environmental standards.

The specific policy support for technology is as follows: (1) The government should increase scientific research investment in manufacturing related fields, support basic and applied research, and promote breakthroughs and innovations in key technologies. (2) The government should promote cooperation between enterprises, universities, and research institutions to accelerate the transformation and application of technological achievements. (3) The government should implement the strategy of strengthening the country with talents, cultivate a group of high-quality talents who understand technology and provide intellectual support for technological innovation in the manufacturing industry. (4) The government should guide and encourage enterprises to transform towards high-end and intelligent manufacturing through policies, reduce dependence on low value-added industries, and enhance the overall competitiveness of the manufacturing industry. (5) The government should encourage enterprises to use advanced technology for production process transformation, improve production efficiency and product quality. (6) The government should improve the incentive mechanism for technological innovation, protect intellectual property rights, and encourage enterprises to engage in original research and development.

In addition, facing the uncertainty of economic policies, manufacturing enterprises need to adopt active strategies to promote their own development through green development strategies and technological innovation strategies.

Manufacturing enterprises should implement green development strategies around production processes, supplier selection, and product production. (1) In terms of production processes, enterprises should reduce energy consumption, carbon emissions, and production costs by improving production processes, using energy-saving equipment, and optimizing energy management.(2) In terms of supplier selection, enterprises should choose environmentally certified suppliers to ensure the sustainability of raw materials, while requiring suppliers to raise environmental standards and jointly reduce the environmental impact of the entire supply chain.(3) In terms of product research and development, enterprises should develop low pollution, easy to recycle, and high value-added products to meet the market demand for green products and improve the market competitiveness of products.

Enterprises should implement technological innovation strategies around four aspects: research and development investment, technical cooperation, technical training, and technical evaluation.(1) In terms of R&D investment, enterprises should increase their R&D budget and focus on breakthroughs in key technologies to improve production efficiency and product quality. (2) In terms of technological cooperation, enterprises should establish cooperative relationships with universities, research institutions, and other enterprises to jointly develop new technologies, accelerate technological innovation and product upgrading. (3) In terms of technical training, enterprises should provide employees with technical training to enhance their skill level, ensure that they can proficiently operate new technology equipment, and improve production efficiency. (4) In terms of technology risk control, enterprises should regularly evaluate and screen emerging technologies, avoid blindly following the trend, and ensure that the technology invested can bring expected economic benefits.

6. Conclusions

Existing research lacks an understanding of the impact of environmental and technological dynamics on RMID. Therefore, to understand the impacts of these two factors on the trend of RMID, this study takes 21 cities as examples to study. The results show that:

Environmental pollution and technology in different cities have different effects on RMID, including promotion, inhibition, and even recession. Through comparison, it was found that the impacts of environment and technology on RMID remain roughly synchronized, but at present, the environmental promotion effect is greater.

The impact of environmental pollution on RMID is relatively small. Two-thirds of cities adopt green development to promote industrial growth, while the development of other cities slows down (3/21), and some cities have a slight downward trend (4/21). This indicates that most cities focus on environmental protection and have a promoting effect on RMID. The remaining cities have a large number of traditional industries due to their weak manufacturing-development foundation. Therefore, they are unable to effectively achieve green transformation, resulting in restrictions on their RMID.

Technology has a prominent impact on RMID. Half of the cities promote industrial growth, but there are still three other situations: development slowdown (3/21), a slight downward trend (5/21), and recession (2/21). This indicates that the current technological development in cities is uneven, with only half of the cities having technological advantages that can promote RMID. The remaining cities have different impacts on the manufacturing industry due to their different technological levels. However, there are still some laws. Medium-tech cities will only reduce the impact on RMID. Cities with weaker technology will limit the development of RMID. Due to technological backwardness, some cities have even caused RMID to regress.

Data availability statement

Data will be made available on request and the relevant datasets can be obtained from the corresponding author.

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CRediT authorship contribution statement

Yanming Sun: Writing – review & editing, Supervision, Resources, Conceptualization. **Shaoshuai Tang:** Writing – original draft, Validation, Methodology. **Zixin Dou:** Writing – review & editing, Supervision, Investigation, Data curation, Conceptualization. **Tao Wang:** Writing – review & editing, Supervision, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The panel data used in this paper are collected from statistical yearbooks, patent databases, local government official websites, etc., not through the distribution of questionnaires. Considering that the data are public data and does not involve human subjects or animal experiments, there should be no ethical approval issues in this paper.

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