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Comprehensive evaluation of urban high-quality development: a case study of Liaoning Province

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Abstract

High-quality development, introduced by China, focuses on the cities' inner level and ignores its manifestations on the external level. Most of the studies on establishing the evaluation index system do not take into account the development of the manufacturing industry, which accounts for a large proportion of the China's economy. This study first redefines the connotation of high-quality development from the internal and external aspects of a city, and provides a new perspective for the definition of high-quality development. Secondly, manufacturing-related indicators are included in the evaluation indicator system of high-quality development to make it more comprehensive and account for the deficiencies of existing research. Liaoning Province is an important industrial estate in China. The problems faced by its development are the epitome of national problems, and it has long been a key area for scholars to study. At present, high-quality development is the only way for the development of Liaoning Province. This is both an opportunity and a challenge to the revitalization of Northeast China. This study was conducted in the Liaoning Province to help it achieve high-quality development, especially in Northeast China, as it has practical significance. On the one hand, it is conducive to leading the industrial transformation and upgrading of Liaoning and Northeast China, optimizing the layout of the regional industrial chain, and promoting the comprehensive revitalization of Northeast China. On the other hand, it will provide decision-making support for further promoting high-quality development practices in Liaoning and even Northeast China. Based on the cross-sectional data of Liaoning Province in 2018, the modified gravity model and entropy method were used to evaluate the high-quality development of Liaoning Province in terms of the four dimensions namely production, living, ecology, and urban connections. The results show that: (1) the internal high-quality development of production, living, and ecology is not synchronized, with significant spatial variation. The dual-core cities (Shenyang and Dalian) have by far the best development quality of production and living. The overall ecological high-quality development presents a spatial "high in the southeast and low in the northwest" pattern, (2) the spatial connection of each city presents a radial and non-equilibrium structure with Shenyang and Dalian as the contact centers, creating a dual-core effect. The quality of ties varies significantly, and cities in fringe and inter-provincial border areas form urban tie "depressions," (3) the internal and external high-quality development lacks coordination; the ecological quality is evenly distributed among all cities, and the ecological civilization construction in Liaoning Province has achieved remarkable results, and (4)

Extended author information available on the last page of the article

Liaoning Province should enhance manufacturing competitiveness and technological innovation capabilities, optimize the equalization of public service resource allocation, improve air quality, and strengthen the radiating and leading role of core cities on surrounding cities and cross-regional cooperation between border areas and neighboring areas.

Keywords High-quality development · Modified gravity model · Entropy method · Liaoning Province

1 Introduction

China's economic development has transitioned from high-speed growth to high-quality development (Hu et al., 2019); however, the economy of Northeast China, especially Liaoning Province, has struggled, and features ongoing problems such as population exodus and an aging population (Han et al., 2019). Promoting the high-quality development of Northeast China is highly valued.

High-quality development is a concept that is unique to China, while foreign studies focus on economic growth. The former Soviet Union economist Kamaeb (1983) was the first to propose the idea of the quality of economic growth, mainly focusing on the increase in production and living materials and improvement in production efficiency and product quality. The quality of economic development is mainly characterized by urban competitiveness, while the quality of urban economic development is improved by strengthening competitiveness (Abdouli & Hammami, 2017; Chorianopoulos, et al., 2010). The concept of high-quality development has been extensively discussed in China based on different research fields and perspectives, but it currently has no unified definition. Based on an economic perspective, Jin (2018) believed that high-quality development refers to that which can provide basic needs under a certain dynamic state. Based on the perspective of the political economy, Zhou and Li (2019) believed that high-quality development comprises the development of productivity and the transformation of production relations. With respect to quantity and quality, Hu (2019) believed that economic development exhibits a commonly observed trend where the focus of development shifts from quantity expansion to quality improvement (high quality), whereas Meng and Xing (2019) defined high-quality development based on concepts, such as innovative, coordinated, green, and open and shared development.

When evaluating high-quality development, previous studies regard the development concepts as the guiding ideology for evaluating high-quality economic development (Ou et al., 2020). Ma and Xu (2020) evaluated the high-quality development of urban agglomerations and prefecture-level cities in the Yellow River Basin. Other studies have also measured the development of a single industry using the connotations of high-quality development, changes in major social contradictions, and economic, political, social, cultural, and ecological perspectives, such as agriculture (Liu, He, et al., 2020; Liu, Li, et al., 2020), manufacturing (Su, 2020), and service industries (Zhao & Shen, 2020) to build a high-quality development power system for internal mechanism analysis (Pu & Jarko, 2018). Based on the perspective of the integration of the Yangtze River Delta, Fu and Chu (2020) used the improved Criteria Importance Though Intercrieria Correlation (CRITIC)-entropy method combined with the weight Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) evaluation model to measure the high-quality development level of the manufacturing industry in Jiangsu, Anhui, Zhejiang, and Shanghai, identifying

innovation, quality, and talent as the main factors influencing the development of the industry. Based on the economic growth fundamentals and social outcomes, Shi and Ren (2018) used the equal weight method to measure and analyze the high-quality development of China's inter-provincial economy. The research objects and empirical areas of these studies are mainly concentrated in urban agglomerations (Fang, 2020; Tu et al., 2020), the Yellow River Basin (Gao & Xu, 2020; Shao et al., 2020; Xu & Wang, 2020a, 2020b; Yu & Fang, 2020), the Yangtze River Basin (Fan et al., 2020), and the Yangtze River Delta (Gao & Jiang, 2020; Tian, 2020).

Generally, high-quality development research emerges based on the concept of high-quality development. At present, research on high-quality development is focused on concept definition, level measurement, and mechanism analysis. Related research has focused only on the internal level of the city and defining high-quality development from the internal economic, social, cultural, and ecological levels of the city, ignoring its manifestations on the external level of the city. On the provincial scale, the evaluation of high-quality development within a city mainly analyzes the development level of a single city; the evaluation of high-quality external development of a city mainly analyzes the level of development between cities. Cities are the basic units that constitute provinces. For the province scale, its development quality may have the synergistic amplification effect of "the whole is greater than the sum of parts," or the interference suppression effect of "the whole is less than the sum of parts" (Tu et al., 2020). Therefore, to judge the quality of development at the provincial scale, in addition to the overallity and balance of the links between cities, it is also necessary to look at the development quality of individual cities within the province. In this way, specific factors and specific cities can be found to "amplification" or "suppression" the overall quality development level of a province according to the level of development quality of a single city. Therefore, this article believes that the inter-city links and the economic, social, and ecological environmental quality of a single city together constitute a provincial-scale development quality system. The construction of its evaluation index system has two shortcomings: First, the relevant indicators of manufacturing competitiveness are lacking. In 2020, General Secretary Xi pointed out that "manufacturing is the lifeblood of China's economy," (Han & Ren, 2020) and the competitiveness of the manufacturing industry should be increased in the evaluation of high-quality development. Second, high-quality development does not specifically refer to a certain field or process, rather, to the higher requirements for various fields (Zhang, 2019). In addition, the ultimate optimization goal of production-living-ecological space[1] and high-quality development is to improve the happiness in the lives of the residents (Jiang & Liu, 2020). Therefore, this study defines the concept of high-quality development based on two levels, namely the internal and external. Based on the characteristics of the industrial structure of the study area, this study adds manufacturing-related indicators to improve the evaluation index system for high-quality development. The internal level includes the production-living-ecological perspective, whereas the external includes the perspective of the city's external connections (Fig. 1). Therefore, high-quality development could connect cities and multiple factors within cities, such as production, living, and the ecological environment.

[1] Production-living-ecological space refers to the general term of production space, living space, and ecological space.

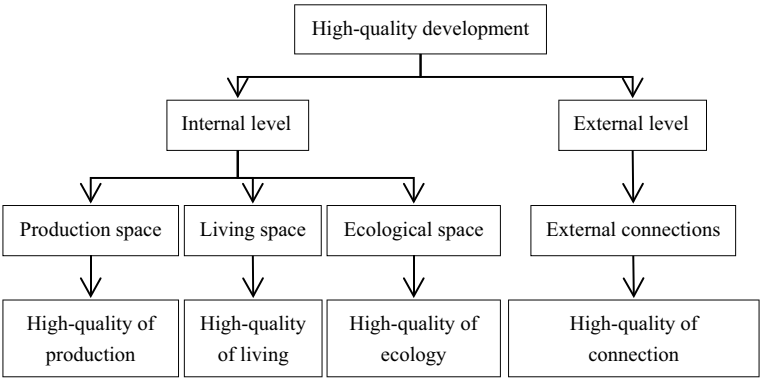

Fig. 1 Conceptual framework of high-quality development

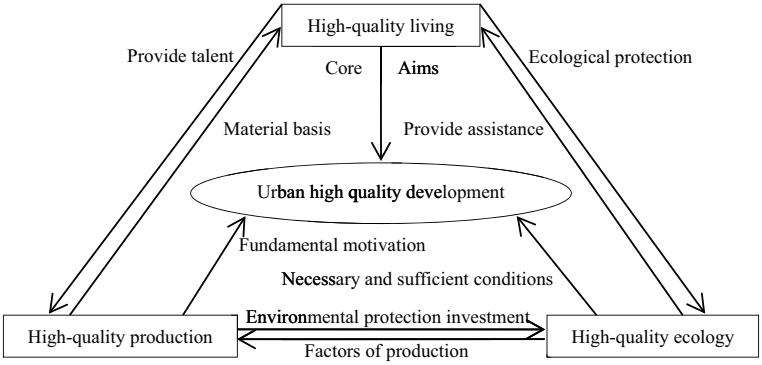

Fig. 2 Theoretical framework of urban high-quality development under the concept of production-living-ecological space

1.1 Internal high-quality development

The internal high-quality development of the city refers to that under the concept of production-living-ecological space. Production-living-ecological space includes production, living, and ecological spaces, which was originally utilized to classify land use functions (Yang et al., 2019). High-quality development under the production-living-ecological concept refers to the unification of the interaction of high-quality production, living, and ecology (Fig. 2). It is different from coordinated development. The coordinated development concept is formed from the spatial dimension, based on the spatial structure of economic development, phased goals, and the sequence of various fields (Li, 2020). It is essentially an overall program and macro orientation. It emphasizes that by improving the rationality of regional division of labor and the completeness of economic structure, it can fully explore its own economic advantages. Coordinated development is to handle the major economic relations in the process of economic development, including uncoordinated regional development, unbalanced urban and rural development, imperfect structural development, unbalanced resource allocation, etc., and pay attention to solving spatial coordination while also solving economic, the

coordination of political, cultural, social, and ecological fields can solve the hidden dangers of uncoordinated development and realize the coordinated development of all aspects of society (Li, 2020). High-quality development inevitably requires the coordination and unity of internal development resources in various regions, fields, and elements. That is, high-quality development emphasizes the integrity of development and the coordination of various development subjects and functional subsystems (Tu et al., 2020). In other words, the internal logical relationship between coordinated development and high-quality development is that the production space, living space, and ecological space promote each other and jointly advance, realize the orderly and free flow of resource elements, and break through coordination. Development bottlenecks are restricted, and a benign development mechanism for the overall healthy development of the economy is formed.

(1) High-quality production

High-quality production refers to the efficient output of the economy and society with the input of certain production factors in the urban space, including high efficiency output, excellent economic structure, high degree of openness to the outside world, and manufacturing competitiveness (Li et al., 2016; Liu & Sun, 2020). High-quality production is the fundamental driving force that promotes high-quality urban development as it is the material basis for achieving high-quality living, and it provides the financial support for high-quality ecology (Li et al., 2021; Zhu et al., 2015). The development of high-quality production helps optimize industrial structure and promote economic development, and determine the quality of high-quality living and ecology (Li et al., 2021; Zhu et al., 2015).

(2) High-quality living

High-quality living refers to the quality of living of residents in urban spaces. In line with the concept of livable living space quality from the United Nations and WTO Conference on Urban Sustainable Development (Liu & Sun, 2020), "high-quality living" as used in this article refers to the comfort, convenience, health, and fairness of residents' lives. High-quality living is the ultimate goal of the coordination and optimization of high-quality production and ecology (Li et al., 2021; Zhu et al., 2015). High-quality living attracts high-quality talents, which in turn supplies talents for high-quality production and boosts high-quality ecology (Li et al., 2021; Zhu et al., 2015).

(3) High-quality ecology

High-quality ecology, which guarantees high-quality production and living, refers to the good condition of ecological resource protection and the ecological environment in urban spaces, including the coverage of green space and the treatment of various pollutants (Liu & Sun, 2020). It provides resources for achieving high-quality production, while providing an ecological guarantee for achieving high-quality living with stable environment and sufficient carrying capacity (Li et al., 2021; Zhu et al., 2015).

The internal high-quality development of the city is reflected in the comprehensive quality level of the three major areas of production, living, and ecology. High-quality production is the inexhaustible driving force and key to achieving internal high-quality development of the city; high-quality living reflects the concept of "people-oriented" development and provides protection for people's lives, which is the core purpose of internal high-quality development; high-quality ecology is a necessary and sufficient condition for achieving internal high-quality development (Li et al., 2016, 2021; Liu & Sun, 2020; Zhu et al., 2015). Urban development at the expense of the environment

will definitely not achieve high-quality development in production and living. In summary, the internal high-quality of a city is an ideal state that is continually targeted.

1.2 External high-quality development

The external high-quality development of the city refers to its high-quality external connections. Within a certain spatial range, the free circulation of various resource elements between cities produces spatial interactions (Tu et al., 2020), forming interactions and connections, and then generating externalities. The cities within the region enhance their economies through collaborative activities and complementary relationships, thereby inducing economic growth, realize joint development, and improve competitiveness (Wang, 2020). Relevant research shows that the degree of connection between cities can impact regional economic growth to a certain extent. Lu (2001) discovered that the "pole-axis model" of regional development models. Qin and Sang (2015) found that the position of a city in a contact network determines the extent of its effect on economic growth. Zhong et al. (2018) determined that the central city has the most significant impact on the economic growth of the region; therefore, urban connections affect the economic and social development of a city as well as the overall space and scale structure of the region and are correlated with the degree of formation and development of the region. The closer the urban connections, the more balanced the spatial interaction and the more mature the regional development (Tu et al., 2020). In summary, the strength of urban connections should be used as a criterion for judging the high-quality level of regional development, where a high quality is reflected in the high degree of urban connections (strength of connections) and the balanced spatial structure of the overall connections.

Section 2, introduces the study area, the evaluation index and methods. Section 3 discusses the characteristics of internal and external high-quality development, as well as the coordination of internal and external high-quality development. Section 4 discusses the strengths and limitations of this study, while Sect. 5 outlines the conclusions drawn from the study.

2 Materials and methods

2.1 Study area

Before the reform and opening up of China, the northeast region was the most important industrial base and the most developed region. It was called the "Industrial Cradle," being the main force that promoted the development and growth of New China and supported the country's economic construction. However, following the deepening of reforms and opening up in China, problems such as the decline of old industries, economic decline, and population exodus became eminent (Han et al., 2019). Liaoning Province exhibits features that are similar to those of other northeastern provinces such as Jilin and Heilongjiang in terms of regional resource endowment, development model, and industrial structure, but its economic development has always been superior to that of the two other provinces (Han et al., 2019).

In addition, the analysis of GDP and population changes in the three northeastern provinces since 2000 (figure a and b in Fig. 3) shows that the GDPs of Jilin and Heilongjiang

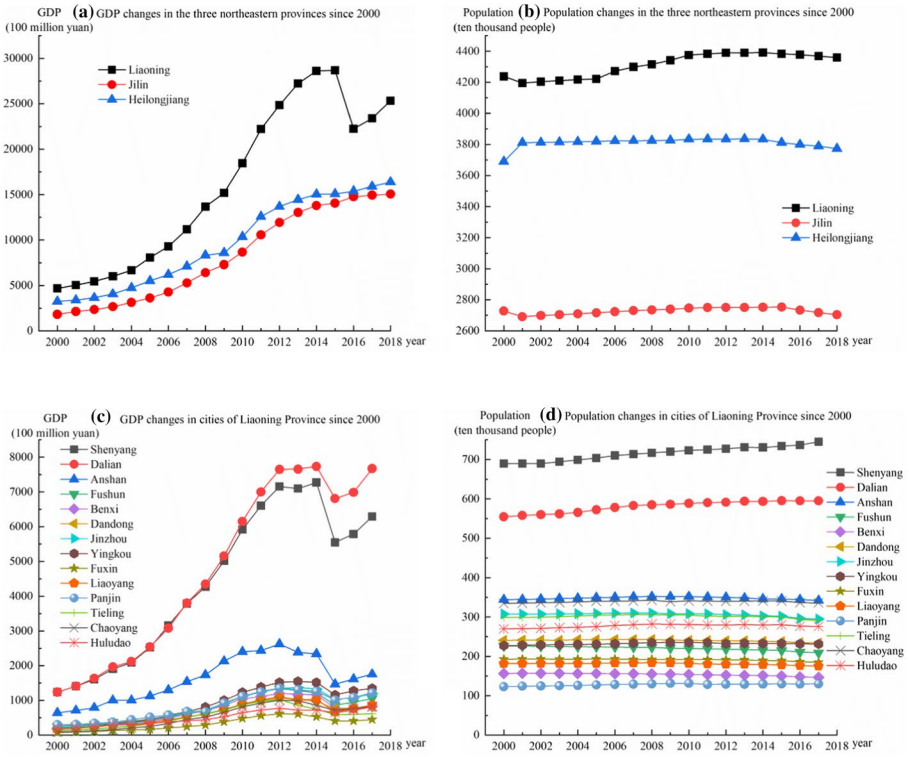

Fig. 3 Changes in GDP and population since 2000

have gradually stabilized after a small increase, with a slight change in population; however, these metrics are significantly different for Liaoning Province. Before 2015, GDP showed a relatively large growth trend, while the population showed a small growth trend. As China's economy has transitioned to a new normal, the GDP of Liaoning Province experienced a "cliff decline" in 2016, and the population has also shown a corresponding downward trend. Since 2016, the GDP has grown while the population has remained on a downward trend. The changes in GDP and population of cities in Liaoning Province are similar to the overall situation in Liaoning Province (figure c and d in Fig. 3). There are 14 prefecture-level cities in Liaoning Province, with Shenyang and Dalian being the most developed. Dalian and Shenyang are far ahead of other cities in terms of GDP, with the two cities' combined GDP accounting for almost half of Liaoning's economy. The strong economic power keeps the population of the two major cities in the first and second place. Anshan is the largest steel industry city in Northeast China, with GDP ranking third and ample population. Yingkou and Panjin followed closely, and the gap between the two cities was very small. As cities in western Liaoning, Jinzhou and Chaoyang have gradually surpassed cities in Liaodong and Liaozhong such as Fushun, Benxi, Liaoyang, and Dandong in recent years. The opening of the Beijing-Shenyang high-speed rail allowed Chaoyang to get rid of its dependence on Jinzhou for transportation and became the "high-speed rail hub center in western Liaoning." Fuxin and Fushun are well-known coal mining cities, but premature mineral development did not bring sustained economic prosperity. Tieling is

located in the mountainous area of northern Liaoning, with more mountains and less land, far away from the core economic circle of Liaoning, and poor economic strength. Although Benxi and Dandong are well-known tourist cities in China, they do not seem to play a significant role in promoting economic development. This indicates that although Liaoning Province has developed, it has not achieved high-quality development and has not met the increasing needs of people, thus leading to a continued outflow of the population to regions that have achieved high-quality development.

Researchers believe that this downturn is the result of the combined effects of internal and external factors, including the macroeconomic downturn (Wei, 2017), inadequate policy implementation (Zhao & Wang, 2017), solidification of institutional mechanisms, and inadequate transformation of government functions (Fan et al., 2016). Since the reform and opening up, China has adopted a phased development strategy. The southeastern coastal areas have taken the lead to become a key area for national investment, and the introduction of market mechanisms has become the mainstream of national policies. Facing "marketization," the old industrial base in Northeast China has encountered unprecedented difficulties: first, the problems left by the planned economic system are obvious, and the industrial structure dominated by heavy industry is difficult to adapt to the economic operation mode under the market mechanism; second, the overall industrialization of the country is inclined to light industry, The current industrial sector structure in Northeast China is "hard to return," and is gradually lagging behind the southeastern coastal areas, which is dominated by light industry (Zhao & Wang, 2017). Since 2013, in the face of the sluggish world economic growth and the downward trend of the Chinese economy, coupled with the inadequacy of various institutional reforms and the lagging industrial transformation and upgrading, the northeast region's economy has fallen into a new predicament after a period of rapid development (Wei, 2017). Large state-owned enterprises in the Northeast China have always enjoyed institutional advantages. In the process of restructuring in Northeast China, the focus of state-owned enterprise reform is on ownership reform. Although it has evolved into a joint-stock company, it still continues the old development model and business philosophy in the form of state-owned shares. The rigid system advantages make the emergence of problems such as backward technology and low production capacity of northeast state-owned enterprises lagging behind, resulting in the ineffective occupation or even waste of social resources (Fan et al., 2016). The regional coordinated development strategy has presented development opportunities. The new development concept has been used to promote high-quality development (An & Li, 2018) to solve the overall issues of development in Liaoning Province. Therefore, evaluating the current level of development quality in Liaoning Province and proposing suggestions for the factors restricting high-quality development will guide the future achievement of high-quality development in Liaoning Province; it is a prerequisite for promoting the realization of the northeast revitalization strategy.

2.2 Evaluation index and weight

Following the principles of comprehensiveness and typicality among others in the selection of indicators, 26 indicators were selected to measure the quality of production, living, and ecological development of cities in Liaoning Province. The indicator system includes three aspects: economy, society, and environment. The economic indicators (Per capita GDP, ect) are mainly reflected in high-quality production, and social indicators (Number of practicing physicians per 10,000 people, ect) are mainly reflected in the quality of living, and

environmental indicators (Green coverage rate of built-up area, ect) are mainly reflected in the ecological high quality. Since the high-quality evaluation articles did not take the manufacturing index into consideration, based on the characteristics of the industrial composition of the region studied in this study, the manufacturing-related indexes were taken into consideration. Manufacturing-related indicators (Proportion of number of manufacturing employees, ect) are the innovations of the study. The quality level characterizes the pros and cons of the development of things. For this reason, the indicators selected in this study are all relative quantitative indicators.

The data were obtained from the Liaoning Statistical Yearbook (2019), China City Statistical Yearbook (2019), and the statistical bulletins of various cities (2019). However, among these sources, some relevant indicators of ecological quality of individual cities were missing. Because the relative changes of ecological quality-related indicators are small from year to year, the data from an adjacent year were selected as a substitute. Alternatively, similar indicators, such as the sewage treatment rate indicator and the water environment compliance rate, were used instead. The entropy method was used to determine the weight of the indicator (Table 1).

2.3 Methods

2.3.1 Modified gravity model

The gravitational model is a mathematical model used to measure the spatial interaction between regions and has been widely used in many fields (Ge & Yu, 2020; Huang & Yang, 2020). The strength of urban connection refers to the degree of spatial interaction between cities, which can be measured using the gravity model (Chen et al., 2013), and the calculation formula is as follows:

$$C_{ij} = \frac{\sqrt{R_i \times E_i} \times \sqrt{R_j \times E_j}}{D_{ij}^2}, \quad C_i = \sum_{j=1}^{n} C_{ij}$$

where C_{ij} represents the strength of the connection between city i and city j, the larger the value, the stronger the city connection and the higher the quality of the city connection; R_i and R_j represent the urban population of city i and city j; E_i and E_j represent the gross non-agricultural production value of city i and city j; D_{ij} represents the distance between city i and city j, C_i represents the strength of external connections of city I (Shi et al., 2016).

2.3.2 Entropy method

Multiple indicators in the evaluation system complicate the integration of problems owing to varying dimensions and orders of magnitude. Before data analysis, this study standardized the original data for each year, and used the entropy method to objectively weight each indicator to obtain a weight matrix. Finally, the weight of each indicator is multiplied by the standardized value and then combined to get the high-quality development index of each city (Pei, 2020). Refer to the study by Pei (2020) for specific methods.

Table 1 Evaluation indicators and weights of urban high-quality development in Liaoning Province

Target layer	Criterion layer	Index layer	Weights	Indicator meaning
The level of high-quality urban development	Quality of production	Per capita GDP (yuan)	0.0980	Reflect economic output efficiency
		Per capita local fiscal revenue (yuan)	0.1015	Reflect the abundance of fiscal revenue
		Proportion of secondary industry (%)	0.0680	Reflect the benefits of industrial structure
		Proportion of tertiary industry (%)	0.0610	
		Number of invention patents authorized per 10,000 people (pieces)	0.1350	Reflect the ability of technological innovation
		Per capita retail sales of consumer goods (ten thousand yuan)	0.1205	Reflect the degree of economic prosperity
		Proportion of total import and export in GDP (%)	0.1394	Reflect the level of opening up
		Proportion of number of manufacturing employees (%)	0.0774	Reflect the development of the manufacturing industry
		Proportion of number of china's top 500 companies (%)	0.1992	
	Quality of Living	Per capita amount of savings at the end of the year (yuan)	0.0588	Reflect people's living standards
		Per capita disposable income (yuan)	0.0595	
		Internet penetration rate (%)	0.0203	Reflect the level of network service
		Pension insurance participation rate (%)	0.0451	Reflect the level of social security
		Medical insurance participation rate (%)	0.2154	Reflect the level of medical service
		Unemployment insurance participation rate (%)	0.0796	Reflect the level of social security
		Urban registered unemployment rate (%)	0.0632	Reflect the level of social security
		Number of practicing assistant physicians per 10,000 people (person)	0.0807	Reflect the level of medical service

Table 1 (continued)

Target layer	Criterion layer	Index layer	Weights	Indicator meaning
		Number of books in public libraries per 100 people (volumes)	0.1676	Reflect the level of education service
		Number of public transport vehicles operated at the end of the year per 1,000,000 people (units)	0.0530	Reflect the level of social security
		Number of gymnasiums per 1,000,000 people (units)	0.0717	Reflect the level of social security
		Number of museums per 1,000,000 people (units)	0.0851	Reflect the level of education service
	Quality of ecology	Green coverage rate of built-up area (%)	0.1695	Reflect the level of environmental greening
		Air quality good rate (%)	0.3034	Reflect the ambient air quality
		Comprehensive utilization rate of general industrial solid waste (%)	0.2409	Reflect the level of environmental governance
		Sewage treatment rate (%)	0.1332	
		Domestic waste treatment rate (%)	0.1530	

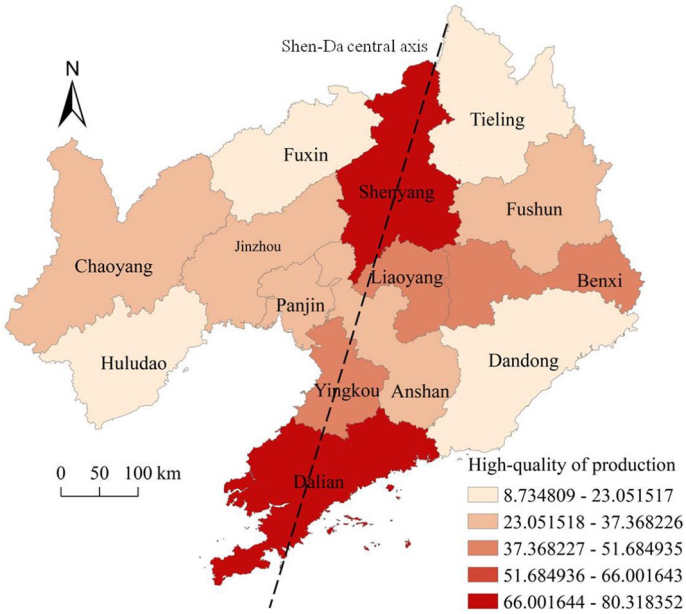

Fig. 4 Pattern of high-quality of production in Liaoning Province

3 Results and analysis

3.1 Characteristics of internal high-quality development

3.1.1 High-quality characteristics of production

High quality production exhibits several unique characteristics: First, the high-quality of production in cities of Liaoning Province features high inequality, which roughly presents a spatial characteristic of "high core and low margin" (Fig. 4), whereas the areas with better production quality are distributed in a "cross" shape. Dalian and Shenyang, being the core cities, have the highest production quality index: 80.318and 69.789, respectively. Eight of the 10 cities whose production quality index is below average are located in the fringe areas of Liaoning Province.

Second, the production quality index is unequal. The top two production high quality indexes exceeded 69, whereas the third-ranked production high quality index was only 49.541; those of the remaining cities ranged between 8 and 49. The production quality index is evidently uneven, while cities with medium and high-quality development are lacking.

Third, the production of high quality features the characteristics of the distance attenuation law. Considering the Shen-Da central axis[2] as the core, the four cities of Panjin,

[2] Shen-Da central axis refers to the central line connecting Shenyang and Dalian.

Yingkou, Anshan, and Liaoyang located in the Shen-Da central axis had an average production quality index of 38.116. Conversely, the average production quality index of the eight cities outside the Shen-Da central axis: Huludao, Chaoyang, Jinzhou, Fuxin, Tieling, Fushun, Benxi, and Dandong, was 22.676.

From the perspective of the evaluation index weight (Table 1), the top three rankings are the proportion of number of china's top 500 companies, proportion of total import and export in GDP and number of invention patents authorized per 10,000 people. Therefore, manufacturing competitiveness, the level of opening up and technological innovation are the leading factors affecting the high quality of urban production, which demonstrates the necessity of including manufacturing competitiveness indexes in high-quality evaluation. The weight of the proportion of number of china's top 500 companies, proportion of total import and export in GDP and number of invention patents authorized per 10,000 people is 0.1992, 0.1394, and 0.1350, respectively. The high production quality scores of Dalian and Shenyang are mainly attributed to their high technological innovation capabilities and manufacturing competitiveness. Dalian and Shenyang produce 2614 and 2943 invention patents annually, respectively, and contain 3 and 7 of China's top 500 manufacturing companies, respectively. Liaoning Province is an important old industrial base in China, with complete industrial categories and systems, especially equipment manufacturing, petrochemical, metallurgy, aviation, and navigation industries, all of which are important in the national industrial layout. To achieve high-quality development of the manufacturing industry, Liaoning Province has identified 100 manufacturing demonstration projects with a total investment of 28 billion yuan, implemented more than 100 major scientific and technological projects, with an average support intensity of 10 million yuan for each project, set up tens of billions of venture capital guidance funds, and increased research and development subsidies and rewards for enterprises.

3.1.2 High-quality characteristics of living

High quality of living shows several unique characteristics: First, the pattern of high-quality of living is similar to that of high-quality of production, roughly presenting a spatial characteristic of "high dual-core" (Fig. 5). The two core cities of Shenyang (72.127) and Dalian (70.623) have the highest quality of living index, while other cities in Liaoning Province namely Tieling, Fushun, Benxi, Dandong, Huludao, Chaoyang, Jinzhou, Panjin, Anshan, Yingkou, Liaoyang, and Fuxin, yielded an average production quality value of only 26.078, which is 6.471 lower than the overall average. This shows that the siphon effect of public service resources is obvious, and the protection of public service resources in other cities is insufficient.

Second, the quality of living index is bounded by the Shen-Da central axis, showing a spatial pattern of high in the east and low in the west. The cities of Tieling, Fushun, Benxi, and Dandong, all of which are located in the east of the Shen-Da central axis, yielded an average living quality value of 29.376, which is 3.173 lower than the overall average (32.549), whereas Jinzhou, Fuxin, Chaoyang and Huludao, located in the west of the Shen-Da central axis, yielded an average living quality value of only 15.328, which is 17.221 lower than the overall average (32.549). However, Liaoyang, Panjin, Anshan, and Yingkou, located in the middle of the Shen-Da central axis, yielded an average living quality value of 33.530, which is 0.981 higher than the overall average (32.549). This shows that the cities on the Shen-Da central axis are more closely connected with the two core cities of Shenyang and Dalian and is more affected by it.

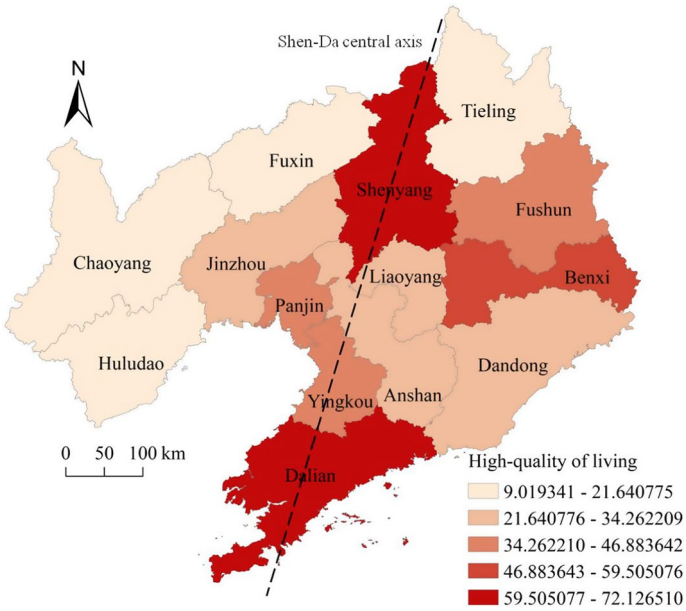

Fig. 5 Pattern of high-quality of living in Liaoning Province

Third, with respect to evaluation indicators, the basic public service resources are excessively concentrated in the core cities. The level of medical and health services, education and culture in Shenyang and Dalian are much higher than those in other cities. For example, the number of licensed assistant physicians accounted for 20.85% of total licensed assistant physicians in Liaoning Province, and the number of public library collections accounted for 46.95% of total public library collections in Liaoning Province. Therefore, optimizing the allocation of public service resources and promoting the equalization of the supply of basic public service resources are the keys to narrow the difference in the quality of life among cities in Liaoning Province.

3.1.3 High-quality characteristics of ecology

The high quality of ecology shows several unique characteristics: First, the high-quality of ecology roughly presents a spatial characteristic of "high in the southeast and low in the northwest" (Fig. 6). Among the top five cities, three are in the southeast (Dalian, Benxi, and Dandong), with an average ecological high-quality index of 79.058, which is 17.496 higher than the overall average. The average value of the ecological high-quality index of Huludao, Chaoyang, and Fuxin in the northwestern region is 59.854, which is 1.709 lower than the overall average. The ecological high-quality index of the core city Shenyang is only 5.043 higher than the average level, ranking low among the 14 cities. Shenyang is a heavily-industrialized city focusing on manufacturing by the state, with more than 60,000 manufacturing enterprises. Its industrial structure leads to a large consumption of coal (Wang et al., 2012). In 2016, the total coal consumption was approximately 33 million tons, which accounted for a large proportion of the primary energy consumption, and was significantly higher than the national average coal share, while clean energy accounted for

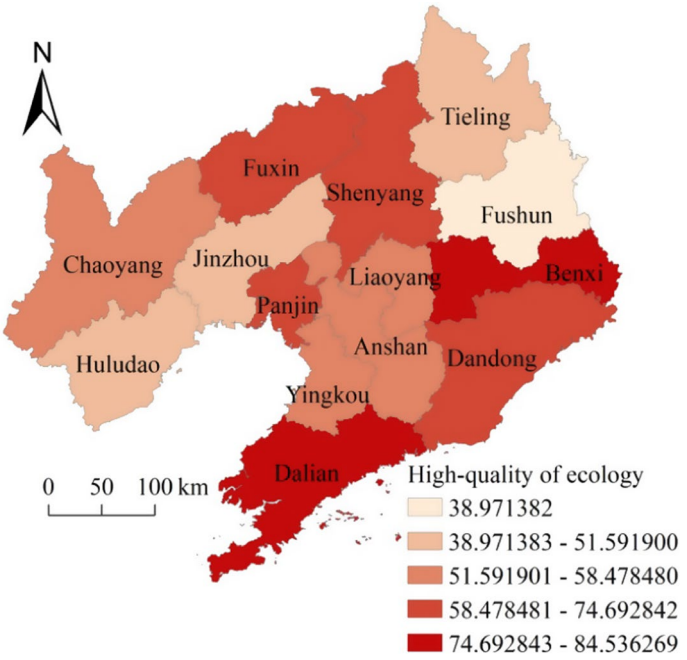

Fig. 6 Pattern of high-quality of ecology in Liaoning Province

less than 13% (Gai & Zhang, 2018). The coal-based energy consumption structure and the winter coal-fired heating method have caused serious smog pollution in Shenyang. At the same time, the green coverage rate of Shenyang's built-up area is only 36.23%, ranking low (Gai & Zhang, 2018). In addition, there are several enterprises in Shenyang that belong to the state's key emission enterprises. Exhaust gas from factories affects air quality, which in turn decreases the quality of the ecological environment (Wang and Wei 2012; Ren et al., 2012).

Second, the positioning of urban functions largely determines the quality of the urban environment (Tu et al., 2020). Six of the eight cities with an ecological high-quality index below the average for high-quality of ecology are petrochemical bases, steel cities, industrial cities, or manufacturing cities. Evidently, the industrial development of Liaoning Province has not benignly interacted with the high-quality ecological development, and has instead caused the deterioration of the ecological environment. The weight of good air quality is significantly higher than that of the four other indicators, indicating that good air quality has the greatest influence on ecological high quality. Therefore, improving the air quality in cities will significantly improve the quality of the ecological environment. To this end, it is necessary to strengthen waste gas treatment, reduce waste gas emissions, and use clean energy to improve the rate of urban air quality, thereby improving the overall ecological environmental quality of Liaoning Province.

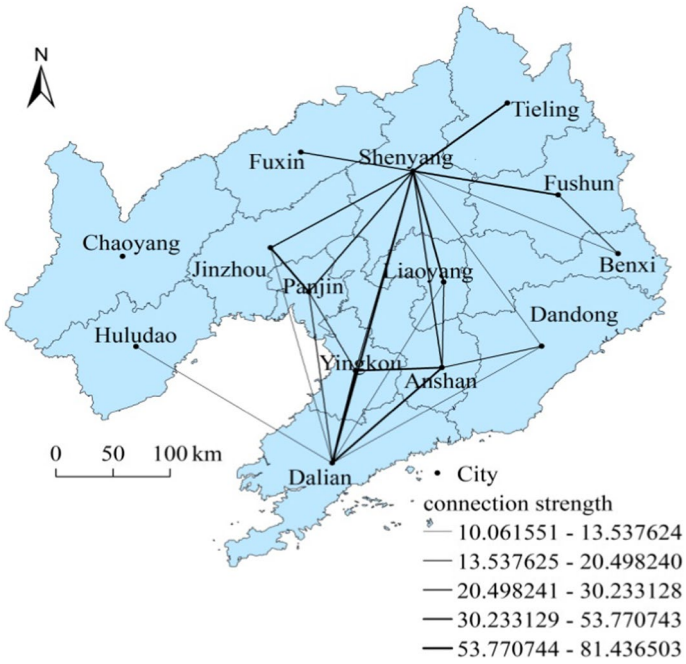

Fig. 7 Spatial distribution of connection strength among cities in Liaoning Province

3.2 Characteristics of external high-quality development

According to the relevant research (Ge & Yu, 2020; Huang & Yang, 2020; Tu et al., 2020) and the principle of data availability, based on the urban population, non-agricultural production value and distance between cities in Liaoning Province in 2018, the modified gravity model was used to calculate the inter-city connection strength index, and ArcGIS was used to analyze and visualize the natural breaks (Jenks), thereby obtaining the hierarchical structure network map of the spatial connection axis between cities in Liaoning Province. To facilitate observation and analysis, only city connections with strength exceeding 10 are used (Fig. 7).

Overall, there are significant differences in the strength of the connections between cities, and the overall performance is a radial non-equilibrium structure with Shenyang and Dalian as the contact centers. Figure 7 shows several unique characteristics: First, the "dual core effect" is unusual. The sum of the intensities of the external connections between Shenyang and Dalian (579.649) accounts for 33.79% of the sum of the intensities of all external connections (1715.516), which is more than 1/3 of the total. This shows that Shenyang and Dalian are China's entry points into Northeast Asia and also node cities of the "The Belt and Road" initiative. They are regional transportation hubs and have greater influence in regional urban connections. Shenyang and Dalian, as the core cities of Liaoning Province, grasp the economic lifeline of Liaoning Province, coupled with the support of government policies, their economic development level is in a superior position, and the bipolar effect is very obvious. For example, most of the important construction projects, major conferences, and special funds flow directly into core cities. The second

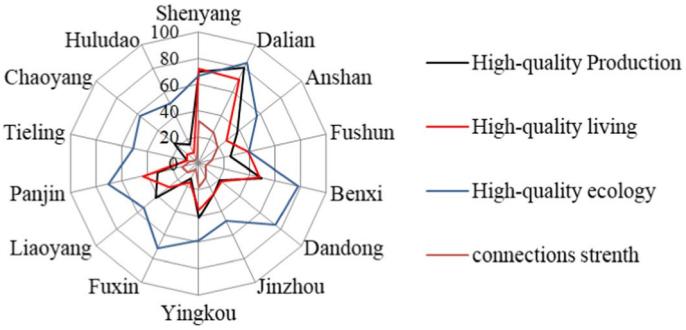

Fig. 8 Radar map of urban high-quality development

is the prominent phenomenon of "strong clubs." The sum of the intensity of external connections (1078.698) of the 5 most connected cities accounted for 62.88% of the sum of the intensity of all external connections (1715.516). Dalian and Shenyang have the closest connection with surrounding cities, and the quality of urban connections is relatively good. Third, there is a huge disparity in the strength of the connections, with those of the central region being stronger than those of the surrounding regions. Using the Shen-Da central axis as the core, the sum of the strength values of external connections to the four cities of Liaoyang, Anshan, Yingkou, and Panjin, located on the periphery of the central axis, are 1.46 times the sum of the intensity of external connections of the seven cities on the periphery of Liaoning Province, Huludao, Chaoyang, Fuxin, Tieling, Fushun, Benxi, and Dandong. Therefore, non-core cities, especially fringe cities far away from core cities, often do not benefit from the radiant driving effect of core cities and fall into the "marginal trap".[3] Therefore, in addition to accepting radiation from the core cities, these cities must also strengthen exchanges with each other and actively seek cross-regional cooperation and collaboration.

3.3 Coordination of internal and external high-quality development

The radar chart is a tool to reflect the coordination between variables in comprehensive evaluation (Liu, He, et al., 2020; Liu, Li, et al., 2020). It draws a high-quality development radar chart based on the high-quality development index (Fig. 8). For better clarity, the value of urban connection strength was reduced by 10 times. In terms of production quality, Dalian and Shenyang are the highest, while Tieling and Fuxin are the lowest. The production qualities of the other cities are relatively low and in close proximity. The quality of living is similar to the pattern of production quality, and most cities have a relatively low level. In terms of ecological quality, Dalian ranks highest. The ecological qualities of other cities are relatively high compared with the quality of production and quality of living. In terms of urban connectivity, Shenyang ranks highest, followed by Dalian, and other cities rank relatively close.

[3] Marginal trap refers to the fact that it is located on the fringe of the administrative area and can hardly receive the radiant driving effect of the core area, which leads to the economic downturn.

First, there is obvious polarization in production, living, and the degree of connection of cities. The core cities, Shenyang and Dalian, show clear development advantages over other cities in the region in terms of production, living, and connections with other cities. Industry in Shenyang is dominated by high-end equipment manufacturing, biomedicine, agricultural products processing, and aviation; industry in Dalian is dominated by shipbuilding, software information, and marine product processing (Peng et al., 2018). The industrial structure is continuously optimized in terms of finance, logistics, tourism, and cultural and creative industries. Continuous development and growth, have lead to a high employment rate and living standards of the population, continuous improvement of the quality of the environment, and the effective promotion of the city's high quality status, makes these core cities the "high-quality development areas" of Liaoning Province. Third, there is little difference among cities in terms of ecological quality. In recent years, cities across the region have increased their investment toward eco-friendly consumption and eco-friendly public services, and have included the ecological environment in their assessments of development to determine whether they are eco-friendly.

4 Discussion

4.1 City's external connections and high-quality development

Since the concept of high-quality development was introduced, it has been defined from different perspectives. Based on the perspective of the new economic normal (Yang, 2018), high quality development is driven by the slowdown of economic growth and the transforming the momentum of economic growth toward innovation-driven development; based on the new development concept (Liu, 2018), high quality development is based on innovation, coordination and green, open, and shared development, which is the development of improved quality, efficiency, fairness, and sustainability. Based on the perspective of supply and demand, high-quality development could address the structural imbalance of supply and demand and achieving efficient and high-quality development on the supply side. However, these discussions focus on the cities' inner not external levels.

The external level of the city comprises the city's external connections. Inter-city connections not only affect the economic and social development of a city, but also the overall space and scale structure of the region. The closer the urban connection, the more balanced the spatial interaction and the more mature the regional development (Tu et al., 2020). Therefore, the connections between cities should be used as a criterion for determining the level of regional high-quality development. High-quality in this criterion should mainly be categorized as a high degree of closeness (connection strength) of cities and a balanced spatial structure of the overall connections.

This study combines the internal and external aspects of cities and redefines the high-quality development from the perspectives of production-living-ecology space and urban external connections, and shows that high-quality development means closer and more balanced external connections between cities, as well as the continuous improvement of production-living-ecology space. The data also provide a new perspective for defining the connotation of high-quality development. Based on the urban population, non-agricultural output value and the distance between cities, we used ArcGIS to calculate the degree of connection between cities in the Liaoning Province. Overall, we found significant differences in the strengths of the connections between cities, while the overall performance was

a radial non-equilibrium structure with Shenyang and Dalian as the contact centers. The results of this study are in line with the development of Liaoning Province and prove the effectiveness of evaluating the high quality of cities from external aspects.

4.2 Manufacturing and high-quality of production

The 2017 Central Economic Work Conference highlighted the need to accelerate the formation of a standardized evaluation system to promote high-quality development that includes policy, statistics, and performance evaluation (Huang and Deng, 2019). Most studies on the establishment of evaluation index system focus on 5 aspects: innovation, coordination, greenness, openness, and sharing (Ou et al., 2020; Xu & Wang, 2020a, 2020b), not on related indicators of the manufacturing industry. The manufacturing industry makes up the large proportion of the Chinese economy; China's industrial sector's value has increased from 11.96 billion yuan in 1952 to 30.5 trillion yuan in 2018, an average annual growth rate of 9%. The industrial added value accounts for more than 40% of total GDP, forming a strong support for GDP growth. At present, the production volume of more than 200 industrial products such as steel, cement, and automobiles in China ranks first in the world. With the continuous advancement of industrialization, China's manufacturing output value surpassed the USA for the first time in 2010 and has been ranked first for many years. Indeed, high-quality development of the manufacturing industry is a strong driver of high-quality development strategy. It is also vital for producing first-class manufacturing brands to enhance China's international competitiveness and prestige.

As an established industrial base, manufacturing remains an advantageous industry and an important engine for the economic development of Liaoning Province; the development of manufacturing industry is indispensable for the development of high-quality production. Therefore, this study added manufacturing-related indicators (number of employees in the manufacturing industry and China's top 500 companies.) to the production high-quality evaluation indicators, in order to determine the status of high-quality development of production in Liaoning Province.

4.3 Restrictive factors

This study analyzed the characteristics of the high-quality development level of Liaoning Province from the perspectives of production-living-ecology space and external connections, and quantitatively evaluated the status quo of high-quality development of various cities in Liaoning Province. However, this study has some limitations. First, we evaluated the high-quality development level of Liaoning Province based on the available "static" data for the latest year, which is effective for accurately grasping the current situation and influencing factors of Liaoning Province's high-quality development from the "spatial" dimension. However, since "development" is a continuous and dynamic process, it is necessary to introduce the dimension of "time" in future studies to explore the changes in Liaoning Province's high-quality development level over time and to further identify the historical factors affecting Liaoning Province's high-quality development. Second, we did not integrate the overall indicators of urban connections with the individual indicators of production, living, and ecology, rather, we evaluated the Liaoning Province based on each indicator. In future, a unified indicator system should be warranted.

5 Conclusion

This study explored high-quality development and used the modified gravity model and entropy method to evaluate the high-quality development level in Liaoning Province. The main conclusions of the study are as follows:

(1) High-quality development is the synthesis of development of the external connections of cities, production, living, and ecological environment. It is a process of developing closer and balanced connections between cities, and the continuous improvement of production, living, and ecological environment.
(2) In terms of internal high-quality development, the patterns of high-quality of production development and high-quality of living development exhibit similarities. Both of Liaoning Province's dual-core cities, Shenyang and Dalian, have the highest development quality. The quality of production and living development in cities far away from these core cities are generally poor, forming "border depressions," and falling into the "marginal zone trap". Shenyang and Dalian have become the most suitable cities for high-quality development in Liaoning Province by virtue of their locational advantages and policy preferences, but have not formed a strong connectivity with peripheral cities, showing obvious polarization. The high-quality development pattern of ecological quality shows a spatial pattern; it is generally high in the southeast and low in the northwest. Compared with Dalian, although Shenyang has better development of high-quality production and living, its ecological environment quality is poor, and it has not achieved full-scale demonstration and a leading role with respect to high-quality development. To improve the high-quality development of production, living, and ecological environment in Liaoning Province, the technological innovation capabilities and manufacturing competitiveness of cities should be greatly enhanced; the supply of basic public service resources should be more evenly distributed, and the effective improvement of the urban atmospheric environment should be promoted.
(3) The external connections of the cities present a radial and non-equilibrium structure with Shenyang and Dalian as the dual-contact centers. The quality of the connections between cities varies significantly and the cities in the fringe areas of Liaoning Province form urban contact "depressions." To improve the closeness and spatial balance of urban ties, exchanges and cooperation between non-core cities should be strengthened, and cross-regional cooperation should be actively sought. The dual-core cities also need to actively build all-round competition and cooperation relationships.
(4) The internal and external high-quality development lacks coordination. The high-quality development of the core cities is robust and balanced. The high-quality development of the other cities is uneven. Ecological quality is more evenly distributed among all cities, reflecting the remarkable achievements of the ecological civilization construction of each city in the Liaoning Province.
(5) The scientific, comprehensive and effective construction of a comprehensive evaluation index system is the key to comprehensive evaluation, and also a difficult issue, which determines the accuracy, rationality, and authenticity of comprehensive evaluation. The comprehensive evaluation index system for the same subject is not static, it should be in line with the actual situation of the study area, and vary with the study area. The ultimate goal of the evaluation of high-quality development in Liaoning Province is to find out various favorable and disadvantaged factors that affect the high-quality development in Liaoning Province, and to effectively put forward policy recommendations

for high-quality development. Therefore, as a major manufacturing province, Liaoning Province needs to add manufacturing-related indicators into its high-quality development evaluation index system. According to the research conclusions, the increase in the high-quality development evaluation index system of manufacturing-related indicators is consistent with the development status of Liaoning Province, and the development suggestions made are more reasonable.

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