AIMS Mathematics

AIMS Mathematics, 8(10): 24825–24847.
DOI: 10.3934/math.20231266
Received: 09 July 2023
Revised: 13 August 2023
Accepted: 15 August 2023
Published: 23 August 2023

http://www.aimspress.com/journal/Math

Research article

Statistical monitoring of economic growth momentum transformation: empirical study of Chinese provinces

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Abstract: Statistical monitoring of the level of economic growth momentum transformation is the basis for implementing quantitative policies for economic growth transformation. Based on theoretical analysis and combined with the process of national economic operation, this paper designs an economic growth momentum transformation monitoring indicator system consisting of four dimensions, supply and demand, factors, consumption and trade, using a comprehensive evaluation method to compile the economic growth momentum transformation level index. Using mainland China's provincial data from 2002 to 2021, we calculated the economic growth momentum transformation level of each province and extracted corresponding characteristics. The research found that the economic growth momentum transformation level of provincial economies in China exhibits stage-wise and dimensional differentiation over time, and it has category agglomeration and tiered transfer characteristics in space.

Keywords: transformation of economic growth momentum; indicator system; statistical monitoring; distribution dynamics; cluster analysis
Mathematics Subject Classification: 62P20

1. Introduction and literature review

In the 21st century, there have been significant changes in the global economic development pattern, accompanied by corresponding transformations in the economic development models of various economies. Developed economies in Europe and America have traditionally relied on deficit financing and personal credit to drive economic growth, resulting in an economic development model centered around credit-based consumption. However, major financial events such as the 2008–2010 U.S. subprime mortgage crisis and the Greek sovereign debt crisis have gradually led to a shift in the economic development model of these developed economies, transitioning from the virtual economy to the real economy [1,2]. In the East Asian region, economies have played a pivotal role in the international economic cycle by providing low-cost labor and products, primarily relying on high savings to promote economic growth. With the enhancement of technological capabilities and a higher global value chain position, East Asian economies have started to focus not only on low-cost labor and products but also on technological innovation and high value-added industries in their economic production activities. As their technological capabilities have improved, East Asian countries have made significant progress in the field of information technology [3,4]. The rapid development of information technology and the wave of digital transformation have provided new impetus and opportunities for economic growth in East Asian countries. Countries such as Russia and those in the Middle East and Latin America, characterized by abundant energy and resources, mainly rely on the provision of energy and resources for their economic growth [5]. However, with the adjustments and developments in energy strategies by countries like the United States, the landscape of energy and resource markets is gradually changing [6]. In general, due to their own conditions, resource endowments and changing development needs, different economies have witnessed a transformation in their economic growth momentum.

Economic growth momentum transformation refers to the conversion of momentum during the process of economic growth. It encompasses two core elements: economic growth momentum and the transformation of economic growth momentum. Momentum is a common term in physics, referring to the energy possessed by an object due to its motion. The concept of momentum has also been introduced in economics as economic momentum. Economic momentum generally refers to the production efficiency generated through innovation and creation, relying on natural resources and regional advantages. From the above definitions of momentum, it can be seen that economic momentum serves as the source of growth for various economic entities. Based on the analysis above and the research objective of this article, the definition of economic growth momentum is further specified as follows: Economic growth momentum refers to the economic benefits generated by humans through various factors, such as result creation and reconstruction, which ultimately manifest in sustainable economic growth. By delineating economic growth momentum, the fundamental connotations associated with it can be derived. First, factors serve as the source of economic growth momentum. One of the contributing factors to economic growth is human beings, who generate economic benefits through their interactions with other factors. Other sources of economic growth include capital, technology and emerging factors like data, which have gradually emerged with the advancement of information technology [7,8]. Second, the integration and reconstruction of various factors constitute another source of economic growth momentum. For instance, when laborers acquire technological knowledge, their productivity improves, leading to the formation of human capital. The full integration of digital elements into various stages of production enhances operational efficiency. The transformation of economic growth momentum refers to the dynamic and progressive process in which two kinds of economic growth momentum alternately evolve under certain conditions. This process is typically characterized by dynamics and gradualness, allowing for the coexistence and mutual promotion of both types of momentum. For instance, in the development of capitalism, economic growth in the early stage of industrial development primarily relied on labor inputs. However, as the economy advances, monopolistic capital emerges, leading to a dominance of capital-driven economic growth.

The quantitative monitoring of the economic growth momentum transformation level mainly is reflected in two aspects. For one thing, the corresponding econometric model is used for analysis. Most literature of this kind is based on existing models and uses corresponding methods to decompose the original parameters to obtain the level of economic growth momentum transformation. For example, the index decomposition analysis method is used to monitor the momentum transformation between the new and the old, which is based on the production function: The labor productivity function is obtained according to the deviation decomposition method based on share, multi-dimensional economic growth momentum is analyzed based on decomposition, and statistical monitoring is carried out [9–11]. Some of the literature has established econometric models to detect the level of economic growth momentum transformation, usually by estimating the relationships between various economic variables and the transformation process and thus determining the key driving factors of transformation [12–14]. In addition, some of the literature has established dynamic stochastic general equilibrium models for monitoring from the perspective of institutional sector equilibrium [15,16] or has adopted factor analysis to determine the basic factors that promote the transformation process to establish an index of the transformation level [17]. For another, the comprehensive evaluation method is used to monitor the level of economic growth momentum transformation. The literature in this aspect is based on the establishment of the indicator system, using the comprehensive evaluation technology to summarize the original indicators and various dimensional indicators layer by layer, obtaining a comprehensive index for statistical monitoring [18]. Zheng et al. constructed an economic growth momentum index from five perspectives (changes in aggregate demand, changes in factor input structure, factor productivity growth rate, factor industrial structure transformation and growth heterogeneity at different periods) by decomposing the total factor productivity under the Cobb-Douglas production function [19]. Li constructed a comprehensive index of new and old momentum by decomposing the total factor productivity under the stochastic frontier analysis method from three aspects: innovation momentum, factor momentum and institutional momentum. They constructed the new momentum index and the old momentum index based on the connotation concepts of new and old momenta, respectively [20].

As China has become one of the major economic powers in the world, its economy has also shifted from high-speed growth to high-quality development, entering a critical period of economic transformation and upgrading, and the way of economic growth needs to be upgraded from factor-driven to innovation-driven accordingly [21,23]. Based on this, the economic growth momentum transformation in mainland China is quite complicated, both in terms of total growth and regional heterogeneity. Therefore, it is of typical significance to study the monitoring of the level of economic growth momentum transformation of mainland China's provinces.

Based on the existing research, the marginal contribution of this paper is mainly reflected in two aspects. First, it involves the development of an economic growth momentum transformation level index based on the operation of the national economy. Previous studies have evaluated economic growth factors comprehensively, but the interrelationships between these factors violate the statistical principle of non-redundancy and completeness. By using the operation of the national economy as the basis for evaluating economic growth momentum transformation levels, this research can better monitor momentum transformation levels while also fully taking into consideration the national economic operating process. Second, this paper summarizes the spatiotemporal evolution of economic growth momentum transformation. While many studies have focused on the results of a comprehensive evaluation, the evolution trend of the level of economic growth momentum transformation has not been analyzed in depth. This paper, therefore, summarizes the fundamental characteristics of economic growth momentum transformation levels based on measured results.

The rest of the paper is structured as follows: The second part describes the method for developing the economic growth momentum index. The third and fourth sections focus on the basic features of the Chinese provincial economic growth momentum transformation level: The third section analyzes the evolution characteristics, and the fourth section presents the spatial features. The fifth part offers the conclusion of the research.

2. Methodology for compiling the index of economic growth momentum transformation level

Index compilation is essentially a multi-index comprehensive evaluation method. Therefore, the methodology follows the general process of a comprehensive evaluation, including steps such as constructing the indicator system, selecting weights and compiling the index.

2.1. Construction and standardization of the indicator system

From the perspective of the status-driven outcome of economic transformation momentum, it encompasses factors such as factor levels, supply-demand structure, trade linkages and efficiency elements. Economic momentum factors serve as the primary basis for decision-making by microeconomic entities, including the investment of new factors, improvements in the efficiency of existing market factors, optimization of overall factor allocation and the application of new business models. The productivity of microeconomic entities plays a foundational role in the mechanism of economic growth momentum transformation. Supply-demand structure encompasses three aspects: supply-side, demand-side and supply-demand equilibrium. The supply-side provides the conditions of institutions, structures and efficiency necessary for the transformation of economic growth momentum. For instance, in a planned economy, the allocation of resources plays a decisive role in the process of resource allocation, achieving optimal allocation of factors and resources [22,23]. The implementation of restrictive policy frameworks on carbon emissions guides industries towards transformation and upgrading, towards high-end and green-oriented development. Additionally, investment in and utilization of research and development innovation contribute to enhancing total factor productivity and labor productivity. On the demand side, investment and trade-related inputs are instrumental in driving economic growth. The direction of investment in the transformation process of economic growth momentum plays a vital role in subsequent sustainable economic development. Supply-demand equilibrium mainly refers to the structural alignment between supply and demand, such as the mismatch between the demand for high-end consumption by residents and inadequacies in high-end production, which pose structural challenges. Trade linkages refer to the interdependence of supply chains and industrial chains influenced by global networks under the backdrop of economic globalization. Achieving synergy with other economic entities at network or chain nodes is crucial for maintaining the resilience of economic development during the transformation of economic growth momentum. Efficiency plays a critically important role in the transformation of economic growth momentum. Efficiency encompasses the efficiency of factors themselves, as well as the efficiency during the operation of economic growth. Upgrading factor efficiency, incorporating new factors and attaining optimal factor allocation contribute to enhancing factor efficiency. Improving economic institutional innovation and the transformation of government functions are involved in enhancing efficiency during economic growth and operation processes. These aspects of economic growth momentum transformation need to be continuously practiced in China's high-quality development process.

In designing the indicator system, the objectives and outcomes of economic momentum transformation should be considered. Different stages have significant roles in the conversion of economic growth momentum across each segment of the national economy, with corresponding transformation goals to facilitate this conversion. On the supply-demand front, the transformation of economic growth momentum is primarily reflected in the production process. The level of production and the structure of product demand are important aspects of economic growth momentum transformation. Elevating growth levels and efficiency in production processes are the goals of economic growth momentum transformation. Factors provide the driving force for economic growth and participate in a series of allocation activities in various segments of the national economy. The proportion of factor remuneration fully reflects the contributions of factor momentum to economic growth, thus primarily impacting the distribution stages of the national economy's operation. The goal of economic growth momentum transformation in distribution stages is to enhance factor efficiency and facilitate optimal factor allocation [24,25]. Consumption momentum transformation reflects the demand for products of different levels in the circulation market by market consumers. It primarily involves the conversion level of circulation stages in the operation of the national economy. In the circulation stage, efficient organizational efficiency is one of the manifestations of momentum conversion. In the consumption stage, the goal of economic growth momentum transformation is to continuously improve residents' quality of life and enhance consumption structure [26–28]. In addition, the level of foreign trade reflects the economic linkages and cooperation between a country and other economies. In the context of globalization, a robust level of foreign trade contributes to accelerating the speed of economic momentum transformation to some extent. Based on the above analysis and following a target-oriented principle, this paper designs a framework for monitoring the level of economic growth momentum transformation based on the segments of the national economy, specifically focusing on the dimensions of supply-demand, factors, consumption and foreign trade.

Upon determining the dimensions of the indicator system, the nature of the specific indicators should be considered. Given that the objective of this indicator system is to monitor levels, the indicators primarily reflect the current status. It should be noted that when evaluating the state indicators and process indicators for the transformation of economic growth momentum, they need to be distinguished. The state indicators are used to illustrate the level of transformation and focus on the analysis of the results in the stages of momentum transformation [29,30]. The stages in this study refer to the results of various momentum transformations each year. The process indicators are mainly explained by the driving factors, so they often represent the influencing factors or driving forces for the transformation of economic growth momentum [31]. Taking research and development innovation as an example, the number of patents obtained is a result indicator that illustrates the ultimate level of momentum transformation, but the number of patent applications is a process indicator to some extent and cannot be used as an evaluation indicator for the level of momentum transformation, so it can only be used as an influencing factor or driving force. Thus, based on principles of importance, scientificity, and feasibility this paper constructs an indicator system for monitoring the level of economic growth momentum transformation, as shown in Table 1.

Table 1. Indicator system for monitoring the level of economic growth momentum transformation.

Evaluation dimension	Indicator name	Indicator code	Measurement method
Supply-demand Momentum	Investment Level	Invl	The growth rate of fixed asset investment
	Investment Structure	Invs	The proportion of tertiary industry fixed investment to total fixed asset investment
	Industrial Structure	Inds	Industrial structure coefficient
	Industrial Upgrading	Indup	The ratio of the added value of the tertiary industry to that of the secondary industry
	Degree of Government Intervention	Gov	The ratio of fiscal expenditure to GDP
Factor Momentum	Human Capital	Hcap	Product of employment and average years of education
	Technological Innovation	Innov	Patent applications and grants
	Capital Efficiency	Cape	The ratio of GDP to total fixed capital formation
	Labor Productivity	Lapro	The ratio of GDP to urban employment
Consumption Momentum	Survival-type Consumption	Sur	The proportion of food and apparel consumption
	Development-type Consumption	Deve	The proportion of residential and daily necessities and services consumption
	Enjoyment-type Consumption	Enjoy	The proportion of transportation and communication, education, culture, entertainment, medical and other goods, services consumption expenditure
Trade Momentum	High-tech Exports	Htech	Export value of high-tech products
	Foreign Trade Dependency	Ftrade	The ratio of total import and export value to GDP
	Foreign Capital Utilization Level	Fcap	The ratio of foreign-invested enterprise investment to GDP

The connotation of each indicator in the design of the indicator system is as follows:

- Supply-demand momentum: This dimension concentrates on the level at which economic growth momentum transforms into activities in sectors like industry and investment. Therefore, the selected indicators encompass three major categories: investment on the demand side, industry on the supply side and the interplay between government and supply-demand dynamics. The growth rate of fixed asset investment measures investment levels, while the proportion of tertiary industry investment signifies the direction of investment in the transition of momentum. Using the industry structure coefficient, the system evaluates the evolution of industrial structure, whereas the ratio of value added between the tertiary and secondary industries serves as a measure of industrial sophistication. To assess the impact of government intervention on market supply and demand, the degree of government intervention is incorporated as an indicator.
- Factor momentum: This dimension examines the transformation of economic momentum from the perspective of factor contributions. Historically, labor and capital have been viewed as crucial

factors for economic growth, with technological innovation gradually gaining recognition as a factor. However, employing labor, capital and technological innovation as specific indicators in the factor transformation indicator system may exclude emerging technologies and industries. Therefore, the indicator system for the factor dimension adopts labor, capital and technological innovation as reference points, while also considering the integration of technology with relevant factors. The factor-side indicators are categorized into two groups: level-oriented and efficiency-oriented. The former includes human capital and technological innovation. Human capital is a composite reflecting the fusion of the labor force and education level. Technological innovation represents the overall level of technological progress following the transformation of economic momentum. The efficiency-oriented indicators primarily focus on the contributions of labor and capital to economic growth. They include capital efficiency, which measures the effect of each unit of capital on economic output, and labor productivity, which indicates the contribution of each unit of labor to economic output.

- Consumption momentum: This dimension assesses the level and pattern of consumption by focusing on consumption structure. Consumption is divided into different levels based on the hierarchy of needs and preferences. Survival consumption relates to essential needs required to compensate for necessary labor and forms the basis of consumption. Developmental consumption satisfies the needs for personal growth and development. Enjoyment consumption enhances the consumer's standard of living and satisfies their desire for pleasure and leisure. The consumption structure undergoes a general pattern of transformation: At lower levels, a higher proportion of expenditure is allocated to basic necessities like food, clothing and shelter. As income increases, the consumption structure gradually shifts towards developmental and enjoyment-oriented consumption, with a higher proportion of expenditure allocated to these higher-level needs.
- Trade momentum: This dimension captures the level of trade and economic exchange between the evaluated entity and other economic entities in an open economy. It represents a significant outcome of momentum transformation. The project monitors trade momentum from three perspectives: high-tech exports, trade dependence and foreign investment utilization. High-tech exports primarily reflect the level of trade momentum transformation. Trade dependence measures the level of economic interaction and cooperation with other economies following momentum transformation. Foreign investment utilization reflects the attractiveness of external capital to the domestic economy.

In the process of summarizing the indicators in the indicator system, original indicators cannot be added together directly due to different dimensions, so they need to be standardized. In this paper, the cumulative probability distribution method is used to standardize the original indicators, with two core steps:

The first step is to calculate the cumulative probability distribution value for each indicator. Assuming that the indicator ξ_i follows a normal distribution with mean μ_i and variance σ_i^2, then the corresponding distribution function of indicator ξ_i is shown in Eq (1). Using this distribution function, the cumulative probability distribution values of the corresponding indicators for each year and province are calculated.

$$F_i(\xi) = \frac{1}{\sqrt{2\pi\sigma_i}} \int_{-\infty}^{\xi} e^{-\frac{(x_i-\mu_i)^2}{2\sigma_i^2}} dx_i, -\infty < x < +\infty. \tag{1}$$

The second step is to convert the cumulative probability value into a standard value ranging from 0 to 100. After obtaining the cumulative probability distribution value corresponding to the respective indicators and samples, multiply the corresponding probability distribution value by 100. Depending on the nature of the indicator, if the indicator is a positive indicator, the value will be directly used as the score for the sample to participate in the subsequent process of comprehensive evaluation. When the indicator is negative, we adopt 100 minus the corresponding sample year value of the indicator as the standardized evaluation value to participate in the subsequent process of comprehensive evaluation.

2.2. Selection of index compilation weights

In this paper, different methods are used for index weighting at different levels. When summarizing the original indicators into various dimensional indices, the entropy weighting method is used for index weighting, with the specific steps as follows:

The first step is to construct a dimensionless indicator matrix. Before weighting, this paper has already standardized the indicators, so the dimensionless indicator matrix is directly used to construct the dimensionless indicator matrix.

$$X = \left(x_{ij}\right)_{n\times m}(i = 1, \dots, 31; j = 1, 2, \dots, m). \tag{2}$$

In Eq (2), x_{ij} represents the -jth indicator of the -ith province; n and m represent the numbers of provinces and dimensional indicators, respectively.

The second step is to calculate the entropy value of the -jth indicator:

$$e_j = -\frac{1}{\ln(m)}\sum_{i=1}^{31} P_{ij}\ln\left(P_{ij}\right). \tag{3}$$

In Eq (3), $P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{31} z_{ij}}$ represents the characteristic weight of the -jth dimensionless indicator value for the -ith province.

The third step is to calculate the weight of the -jth indicator:

$$w_j = \frac{1-e_j}{31-\sum_{i=1}^{31} e_{ij}} e_j = -\frac{1}{\ln(m)}\sum_{i=1}^{31} P_{ij}\ln\left(P_{ij}\right). \tag{4}$$

When using the entropy weighting method to weigh each indicator, it is important to note that the entropy weight of each indicator is calculated based on the annual distribution. This ensures the dynamism of the comprehensive evaluation process. This approach is considered for the following reasons: The transformation process of economic growth momentum is dynamic, especially for spatial panel data, and some indicators have lower variability during the transformation process or have already achieved the predetermined goals during the transformation process. At this time, the weight of the indicator needs to be lighter, so a dynamic weighting method is required.

Given the possibility of non-robust scenarios in the weighting process for each dimension and the subjectivity caused by organizational behavior, as well as the objectivity of the impact of each dimension on the process of economic growth momentum transformation, the paper uses the Analytic Hierarchy Process (AHP) to adapt to the combination of subjective and objective weighting, which is more consistent with the complexity of the economic growth momentum transformation process.

When further summarizing the various dimensions, the AHP is used for weighting. The specific steps for determining the weights are as follows:

First, in the established hierarchical structure model, the importances of the four dimensions are compared in pairs.

Second, the matrix structure is determined. By comparing the relative importances of the four dimensions to the transformation of economic growth momentum, the importance matrix $A = (a_{ij})_{n\times n}$ for each dimension is obtained, where a_{ij} represents the comparison value of the importance of indicator i and indicator j. If the value is greater than 1, indicator a_i is relatively more important than indicator a_j, where $a_i \times a_j = 1$. The specific values are shown in Table 2:

Table 2. Scale table for pairwise judgment matrix.

Scale	Meaning
1	Indicates that two indicators have the same level of importance
3	Indicates that the first indicator is slightly more important than the second
5	Indicates that the first indicator is significantly more important than the second
7	Indicates that the first indicator is strongly more important than the second
9	Indicates that the first indicator is extremely more important than the second
2,4,6,8	Indicates the middle value of the adjacent judgments mentioned above
Reciprocal	$a_{ji} = 1/a_{ij}$, indicating the ratio of the importance of indicator a_j to indicator a_i

Third, the consistency ratio is calculated to check the consistency of the weights.

Fourth, the weight of each dimension is calculated using the arithmetic mean method[1].

2.3. Compilation of the economic growth momentum level index

We sought the opinions of experts in the macroeconomic industry and macroeconomic research in universities to rank the importance of each dimension, and all questionnaire responses were valid[2]. The arithmetic means of the weights determined by each expert were used to determine the final weights of each indicator, which are 0.2231, 0.4042, 0.1726 and 0.2002. According to the mapping function, the original data are converted, and the weight of the index layer is obtained through the entropy weight method. Then, the sub-indices of economic growth momentum transformation in each province are calculated. Based on this, after assigning the weights of corresponding dimensions to each sub-index of economic growth momentum transformation, the total index of economic growth momentum transformation can be constructed. The specific calculation formula is as follows:

$$Index = 0.2231 * \mathrm{D1} + 0.4042 * \mathrm{D2} + 0.1726 * \mathrm{D3} + 0.2002 * \mathrm{D4}. \quad (5)$$

[1]Given the maturity of the Analytic Hierarchy Process (AHP) steps, specific calculation processes such as consistency checks and weight calculation methods can refer to other relevant references and will not be further elaborated here. The commonly used methods for calculating hierarchical weights include the arithmetic mean method, square root method and eigenvector method. In this case, the arithmetic mean method was used.

[2]We constructed a pairwise comparison table and sent it to 32 experts from different research and practical departments. The AHP method was used to calculate the weights of each dimension determined by different experts, and then the weights were arithmetically averaged to determine the final weights of each indicator. After calculating the weights, we used the reset sampling method to sample a random number of the survey questionnaires to verify the robustness of the weight calculation results, and we found that the results were robust.

3. Evolutionary characteristics of China's economic growth momentum transformation level

3.1. Data sources and description

The data description includes three dimensions: time, space and frequency. In terms of time, this paper selects the sample period from 2002 to 2021. Selecting 2002 as the starting point is due to two aspects: the phased process of China's economic system reform and changes in the global economic structure. In terms of space, this paper selects provincial regions in mainland China as specific research samples. The selection of provincial regions is also due to two aspects: the constraint of the administrative management system and the driving mechanism for economic growth momentum transformation, and the correlation between the series characteristics of provincial regions and economic growth momentum transformation [32]. The data frequency is annual, which is selected based on data availability.

The data used in this paper mainly come from the following sources: first, the *China Statistical Yearbook* of various years. It is worth noting that some data collected from the yearbook cannot be directly used for the indicator measurement but need to be sorted or recalculated, such as human capital data, which are not directly obtained from the yearbook but calculated with the data of employment and average education years. In addition, relevant data are adjusted according to the latest statistical caliber. Second, the *High-tech Industry Statistical Yearbook* of each year was used. The data relating to high-tech products in the indicator system come from this yearbook.

3.2. The overall evolution of the characteristics of the transformation level of China's economic growth momentum

According to the abovementioned methods, relevant provincial data were collected to calculate the index of China's economic growth momentum transformation. The results of the calculation are shown as the total index of economic growth momentum transformation of each province, which includes four sub-indices of four dimensions: supply and demand, factors, consumption and trade momentum. To provide a basic description and analysis of the index of China's economic growth momentum transformation, this part briefly analyzes the temporal, spatial and dimensional correlations of the momentum transformation.

Based on the calculation results, the annual momentum transformation index and the mean value of each dimension were calculated to form a time-series line chart, as shown in Figure 1.

From Figure 1, it can be seen that the overall trend of economic growth momentum transformation is stable with certain periodicity. The overall index of economic growth momentum transformation is relatively stable mostly in the range of 45–48. The economic growth momentum showed two significant periodical characteristics during the sample period, namely, the period from 2002 to 2009 and the period from 2010 to 2021. From 2002 to 2009, the economic momentum transformation was relatively stable, while the economic momentum transformation showed a significant increase after 2010. However, after the outbreak of the COVID-19 pandemic in 2020, the economic momentum transformation index continued to decline for two consecutive years. This significant periodicity is related to major events. The critical point in 2009 was strongly related to the global economic crisis. Since 2002, interest rates of countries such as the United States have first dropped and then risen, and the real estate market has seen an economic phenomenon of being hot first and then cold. In 2007, the sharp increase in subprime mortgage defaults in the US led to shocks, panics and crises in the international financial market. Some EU countries like Greece also experienced a sovereign debt crisis in 2008. These global financial crises have had a significant impact on the economic growth momentum. At the same time, the turning point of the momentum transformation in 2020 was due to the economic impact caused by the COVID-19 pandemic. Since the outbreak of the pandemic, it has had a restraining effect on the production, consumption and other links of various countries worldwide, thus hindering momentum transformation.

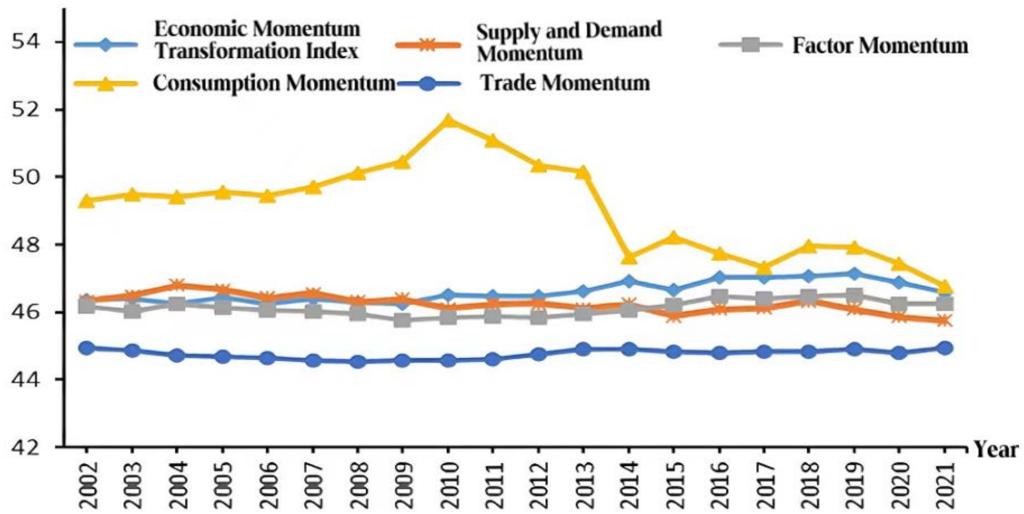

Figure 1. Line chart of the evolution of the momentum transformation index and its dimensions over time.

From the various dimensions of momentum transformation, the indices of all dimensions, except for the consumption momentum, have a basic consistency in trend, but there are still certain differences among the dimensions. As shown in Figure 1, from the various dimensions of the total momentum index, except for the consumption momentum dimension, the indices of other dimensions are basically in a relatively stable state. In terms of the effects of the four dimensions on momentum transformation, the consumption momentum has always been in the leading position, while the trade momentum is in the lowest position. Before 2014, the supply and demand momentum was in a secondary position, but with the rapid development of digital factors, it surpassed the supply and demand momentum and became second only to the consumption momentum. In terms of the time trend of each dimension, the consumption momentum has the largest amplitude of change. From 2002 to 2010, the consumption momentum rose rapidly and peaked in 2010. Subsequently, it decreased rapidly until it became stable after 2014. However, affected by the COVID-19 pandemic, the consumption momentum once again declined since 2019. The supply and demand momentum has been in a stable state, but it has also exhibited certain cyclical characteristics. The factor momentum was relatively stable in 2010, but after that, the upward trend became obvious, and it gradually became the second momentum of economic transformation. The trade momentum has been generally stable, and with the high-level opening up of the economy, its role in economic momentum transformation will be further enhanced. It should be noted that while investment is widely recognized as a crucial driving force behind China's economic growth, this does not contradict the dominant role of consumption momentum in the transformation of economic growth momentum [33]. First, economic growth and the transformation of economic growth momentum are two distinct concepts. Second, the transformation of economic growth momentum is a complex process. Although investment plays a significant role in China's economic growth, it does not exclude the presence of consumption momentum as the dominant force in the transformation of economic growth momentum.

From the stage trend, the stage trends of different dimensions also appeared around 2010, which is related to the global economic crisis in 2008.

We drew a time series line chart of the annual standard deviation of the economic growth momentum index and its various dimensional sub-indices, as shown in Figure 2.

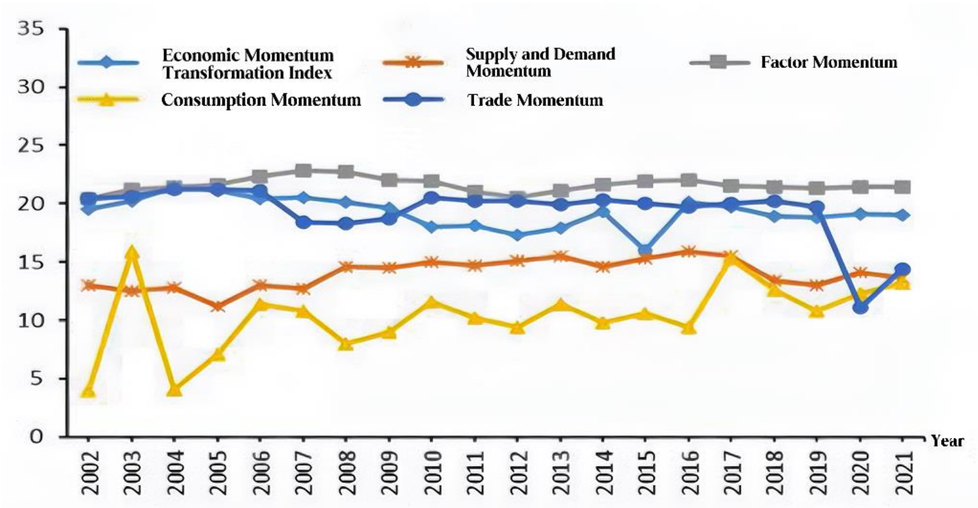

Figure 2. Time series line chart of the standard deviation of regional economic momentum transformation.

From Figure 2, it can be seen that the total index of the economic growth momentum transformation has a certain degree of fluctuation, but the fluctuation degree is not significant. During the period from 2002 to 2021, regional differences have always existed, but the fluctuations are not significant. Among them, from 2004 to 2012, the regional differences in economic momentum transformation were reduced, and there was a trend of convergence in economic momentum transformation among various regions. However, after that, the differences in economic momentum transformation among various regions returned to the original levels. Based on this, it can be inferred that in the process of momentum transformation in China's provincial economies, different provinces are balanced, and the process does not have divergent characteristics due to the promotion of momentum transformation.

By comparing the standard deviations in different dimensions, we found certain differences between different dimensions. In the four dimensions of economic momentum transformation, the difference in the factor momentum is the largest, followed by the trade momentum, with smaller differences in the supply and demand momentum, and the smallest differences exist in the consumption momentum. In terms of the evolution over time in each dimension, the regional difference in the factor momentum is not only high but also has the potential to continue to widen. Especially after 2012, the difference in the factor momentum has further widened, and the performance of regional differences in the factor momentum is obvious. The possibility of long-term high differences in factor momenta in different regions is related to the regional distribution. The natural differences in foreign trade between the eastern coastal areas and the northwestern inland areas have promoted the transformation of trade momenta in various areas. In 2020, affected by the COVID-19 pandemic, foreign trade in various regions was severely restricted, and the difference in the trade momentum was significantly reduced. The difference in the supply and demand functions in various regions continues to increase. This may be related to the local industrial structure adjustment, and the differentiation of industrial division of labor in various regions has led to a shift in supply and demand momenta in various regions, resulting in a significant increase in differences. The difference in the consumption momentum in various regions shows an increasing trend of fluctuations. Before 2005, except for the impact of SARS in 2003, the differences in consumption momenta in various regions were relatively low. From the year 2006 to 2016, although the difference in the consumption momentum fluctuated, it maintained a certain level. After 2017, the differences in consumption momenta in various regions further widened. Based on this, due to resource endowment variations in different regions, combined with the gradual introduction of the digital economy into the process of momentum transformation, various provincial regions show a certain degree of divergence in the factor momentum transformation.

3.3. Evolution trend of China's economic growth momentum transformation level

To examine the evolutionary characteristics of momentum transformation and its various dimensions, this paper uses kernel density estimation to investigate its spatial evolution characteristics. Kernel density estimation is a non-parametric method used in probability theory to estimate unknown density functions. It was proposed by Rosenblatt (1955) and Emanuel Parzen (1962) [34,35]. Kernel density estimation is a commonly used non-parametric method for scholars to address imbalanced distributions. It solves the problem of the histogram being too rough and having poor estimation accuracy as the earliest non-parametric kernel density estimation method. It uses smoothing methods to replace the histogram with a continuous density curve, which can better describe the distribution shape of random variables.

Assuming that the density function of the random variable momentum transformation index is $f(x)$, the probability density at point x can be estimated by the following Eq (6).

$$f(x)=\frac{1}{Nh}\sum_{i=1}^{N}K(\frac{X_i-x}{h}) \quad (6)$$

In Eq (6), N represents the number of observed values for the provincial momentum transformation index, h represents the bandwidth, and $K(\cdot)$ represents the kernel function, which is a weighting function or a smoothing conversion function. The kernel function has various types, such as Gaussian kernel, triangular kernel, etc. X_i is the observed value of the independent and identically distributed momentum transformation index or each dimension index, and x is the sample mean.

The bandwidth h in the probability density estimation formula determines the smoothness of the density curve. If the bandwidth h is larger, the curve will be smoother, and the selection of the bandwidth h will to some extent determine the shape of the density curve. In practical research, if there are more samples, the requirement for the bandwidth h should be smaller. The bandwidth h is a function of the sample N and must satisfy the following conditions:

$$\lim_{N\to\infty} h(N) = 0,$$

$$\lim_{N\to\infty} Nh(N) = N \to \infty.$$

Since there are many types of kernel functions, for the problem studied in this paper, the commonly used Gaussian kernel function will be selected to estimate the distribution momentum of China's momentum transformation.

Since kernel density estimation does not have an explicit functional expression, it is necessary to depict the graph to analyze the changes in the distribution of provincial momentum transformation. By depicting the distribution pattern, the location changes of the momentum transformation distribution can be observed, which can be used to illustrate the high and low levels of the momentum transformation index and its various dimensions. The distribution shape can illustrate the size of the distribution gap, the polarization phenomenon of provincial momentum transformation and its various dimensions. The extensibility of the distribution of the provincial momentum transformation index and its dimensions can illustrate the size of the distribution gap. Based on this, the kernel density estimation of the total momentum transformation index and its various dimensions is shown in Figure 3.

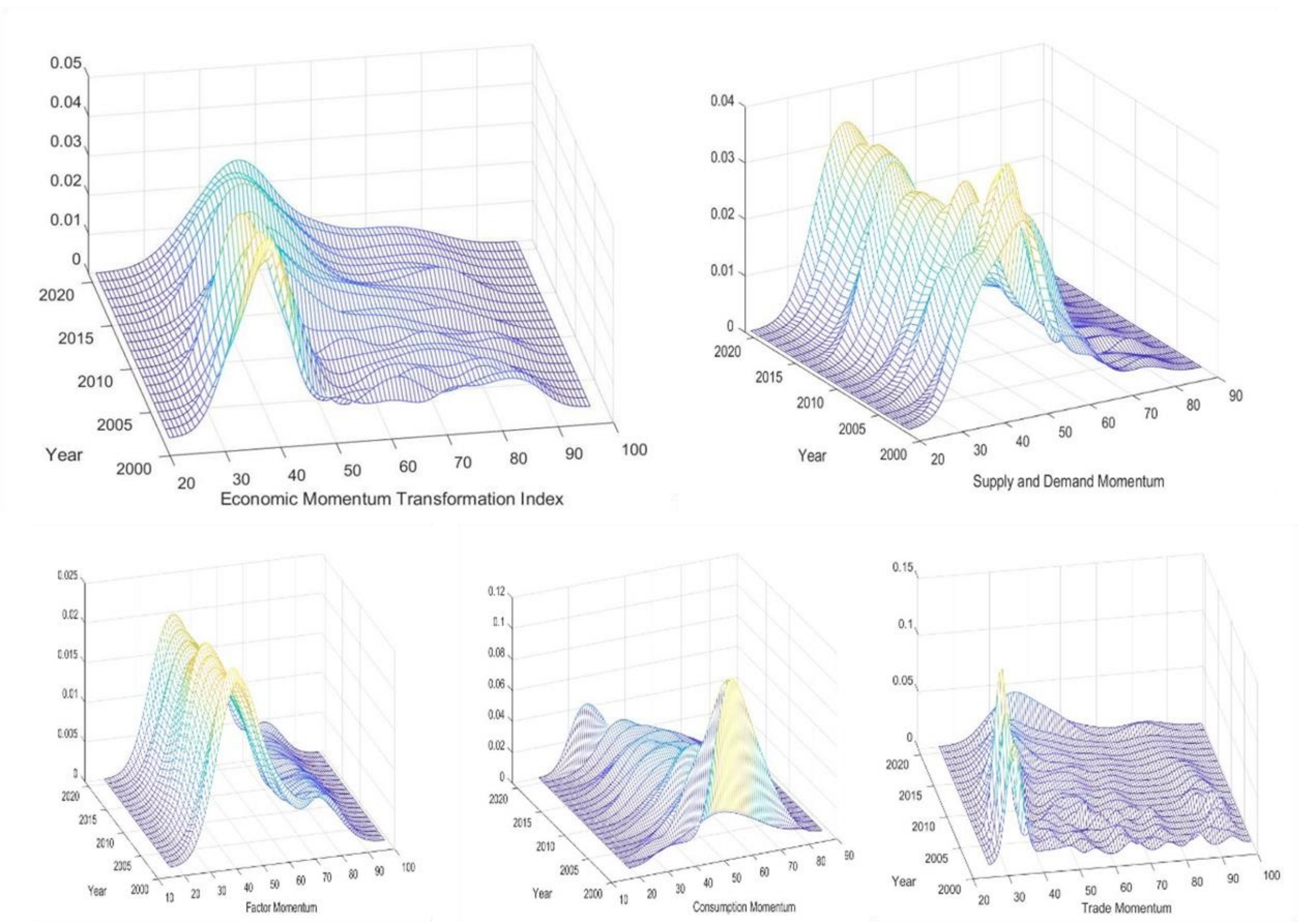

Figure 3. Evolution of kernel density estimation of economic momentum and its dimensional index.

According to Figure 3, this research intends to analyze the overall index of economic momentum transformation and its dimensional indices by comparing them. From the perspective of the total index of momentum transformation, the overall trend shows a phased and rightward movement. Specifically, the characteristic analysis shows that, first, from the perspective of temporal evolution, the distribution of the total index of momentum transformation in Chinese provinces shows a rightward movement, indicating that the degree of momentum transformation in provincial regions is gradually improving over time. With the evolution of time, the momentum transformation in provincial regions also shows a certain stage, which can be divided into two stages with differences, namely, 2002–2013 and 2014–2021. The division of these two stages is based on the time when China entered the new normal of the economy, indicating that China began to guide the economic momentum transformation with policy measures around 2013, and its effect has gradually been reflected in subsequent periods. Second, from the perspective of the peaks of the density function curve of the total index of momentum transformation in provincial regions, there is no significant change or trend in the distribution characteristics, indicating that the differences in the index of momentum transformation among different provinces are not obvious, and overall, they are within an acceptable range of fluctuation. Third, the density curve reflecting the total index of provincial momentum has always been in a unimodal state, indicating that the characteristics of changes in provincial momentum indices are consistent, and there is no trend of multi-polar development.

From the perspective of the comparison of the evolution of various dimensions, different dimensions have significant differences in their evolution. The specific characteristics of each dimension are analyzed as follows. First, the characteristic of the supply-demand momentum has cyclical fluctuations. The supply-demand momentum remains stable within a certain range and has cyclical fluctuations during the evolution process. The supply-demand momentum mainly refers to the transformation of momentum caused by demand in production, and its level changes are reflected in the industry structure. The supply-demand momenta of different provinces in China remain within a certain range, indicating that different provinces have some fluctuations in the industry, but the overall change in structure is not significant. The supply-demand momentum also has cyclical fluctuations which are closely related to the business cycle. Second, the evolution process of the factor momentum is relatively stable and has a double peak and a rightward trend. Factors in economic growth have strong asymptotic characteristics, and they are relatively stable during the evolutionary process, which fully demonstrates that the transformation of the factor momentum needs to be driven by technological factors. Meanwhile, the kernel density distribution curve of the factor momentum shows a bimodal feature, indicating the polarization of the factor momentum among different provinces, and the distribution function also has a rightward trend, indicating that the transformation of factor momentum is gradually strengthening over time. Third, the evolution of the consumption momentum has a large fluctuation, and its peak is gradually decreasing. Consumption momentum is based on the evolution of consumption structure. According to the evolution theory of consumption structure, mankind's consumption structure gradually evolves from survival-oriented consumption to enjoyment-oriented consumption. The large fluctuation of consumption structure indicates that there are significant differences in consumption structure among different provinces, and there is a strong correlation between the evolution of consumption structure and the economic output supply-demand structure. Fourth, the peak of the trade momentum is changing, and the distribution function has a rightward trend. Trade momentum is evolving from multi-peak to single-peak, demonstrating that the regional trade division of labor among provinces is gradually balanced. Against the backdrop of the full development of interconnectivity in recent years, the consumption structure is gradually balanced. The distribution function of consumption momentum has a rightward trend, indicating that the role of consumption momentum in the transformation of economic momentum is gradually increasing. Through the above analysis, the momentum index transformation of each dimension has significant differences, but overall, each dimension's role in the transformation of economic momentum is gradually increasing.

4. Spatial characteristics of China's economic growth momentum transformation level

4.1. Overall characteristics of spatial clustering of China's economic growth momentum transformation level

To investigate the spatial characteristics of China's provincial economic growth momentum transformation, this research conducted a cluster analysis on the sample provinces based on various sub-indices of momentum transformation to investigate their spatial characteristics. The panel data of economic momentum transformation were clustered using the average distance method, and the cluster diagram is shown in Figure 4.

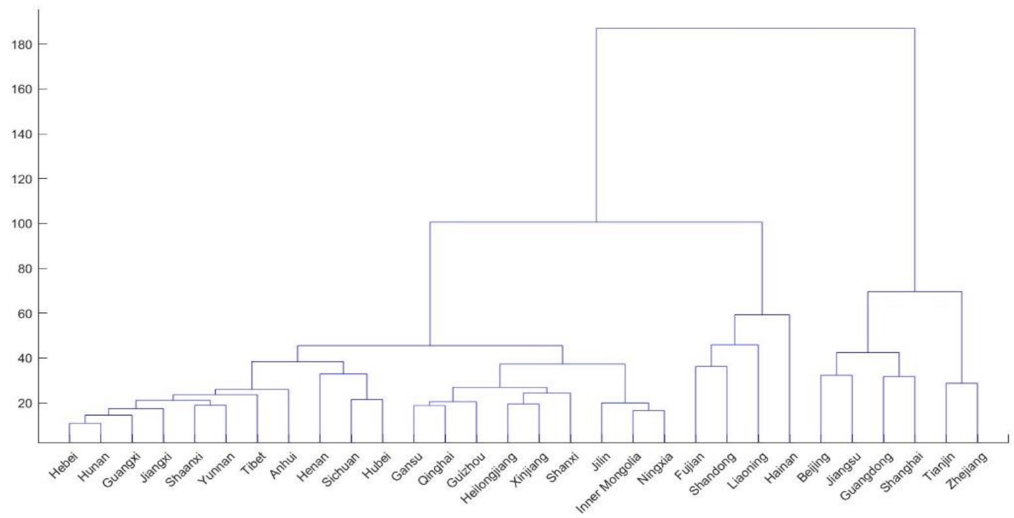

Figure 4. Cluster diagram of provincial momentum transformation index panel data.

Figure 4 shows that different provinces can be initially divided into three categories based on the cluster diagram, and there is an agglomeration effect between categories. From the perspective of the three categories, the first category includes provinces such as Anhui, Gansu, Guangxi Zhuang Autonomous Region, Guizhou and Hebei, which are mainly located in Central and Western provinces. The second category includes four provinces, namely, Fujian, Hainan, Liaoning and Shandong, which have coastal resource endowments, but their economic potential has not been fully realized. The third category includes provinces such as Beijing, Guangdong, Jiangsu, Shanghai, Tianjin and Zhejiang, which are mainly developed Coastal provinces. From the perspective of the agglomeration effect of momentum transformation in provincial regions, the agglomeration effect is concentrated in the first category of Central and Western provinces, which indicates that momentum transformation has not played a demonstrative role in developed coastal provinces in Eastern China. Considering the implementation of Chinese policies in practice, different provinces, especially Central and Western provinces, have a strong imitation effect driven by the “local championship,” and this imitation effect is less prevalent in developed Coastal provinces in Eastern China, resulting in the agglomeration effect of momentum transformation being more reflected in Central and Western provinces [36,37]. In addition, the level of economic activity in China is strong in the East and weak in the West, which creates a need for alternatives in economic development and momentum transformation, and this need is determined by the regional hierarchy of China's economic development. Provinces in the West are generally less developed than those in the East, so traditional industries need to be replaced through industrial transfer during the process of momentum transformation. The industrial transfer is more about Western and Central provinces taking over industries from the East, giving the Eastern Coastal regions an advantage in momentum transformation [38–40]. Furthermore, due to resource endowments, such as ports in the Eastern region, these areas are more closely connected with the global economy in terms of momentum transformation and the aggregation of new emerging industries [41,42].

To further examine the central characteristics of different categories, the central characteristics of each category were calculated and are shown in Table 3.

Table 3. Cluster centers of regional economic momentum transformation.

Category	Province	Center Value				
		General index	Supply and demand	Factors	Consumption	Trade
The first category	Anhui, Gansu, Guangxi Zhuang Autonomous Region, Guizhou, Hebei , Henan, Heilongjiang , Hubei, Hunan, Jilin , Jiangxi, Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, Qinghai, Shanxi, Shanxi, Sichuan, Tibet Autonomous Region, Xinjiang Uygur Autonomous Region, Yunnan, Chongqing,	35.28	44.19	46.88	49.63	43.96
The second category	Fujian, Hainan, Liaoning, Shandong	56.23	46.50	48.83	51.43	50.08
The third category	Beijing, Guangdong , Jiangsu, Shanghai, Tianjin, Zhejiang	79.81	53.33	41.67	45.63	44.02

From Table 3, it can be seen that there are significant differences in the characteristics of regional momentum transformation across different categories. In terms of the general index, the momentum transformation index of the three categories ranked from high to low is: the third category, the second category and the first category. The average scores of different categories are very different. The average score of the third category is 79.81, which is more than twice that of the first category (35.28). Each province has different scores in different dimensions. Provinces in the first category do not have significant advantages in each sub-dimension, and factors and consumption momenta are slightly more advantageous compared to other dimensions in different categories. The four provinces in the second category have certain advantages in factors, consumption and trade momenta, but this advantage is relative, and there is no significant advantage in scores. Provinces in the third category have a very significant advantage in the supply and demand momentum, which is almost 10 points higher than the first category. In terms of classification comparison, the characteristics of different category provinces are also very obvious. The economic momentum transformation in provinces in the first category is relatively low but shows an upward trend. Provinces in the first category are mainly located in the Central and Western regions, and their economic momentum transformation has a certain lag. At the same time, the momentum transformation base of this category of provinces is relatively low, so policies can have a more obvious guiding effect on these areas, and their momentum transformation general index and sub-dimensions are all showing an upward trend. The economic momentum transformation in provinces in the second category shows a certain asymmetric change of decline and slow rise. As mentioned above, the provinces in the second category are located in the Coastal areas, but their institutional advantages have not been fully utilized, so the economic momentum transformation has not been fully promoted. At the same time, there is an asymmetric trend of momentum transformation within the provinces, and this trend has an upward momentum. The economic momentum transformation of provinces in the third category shows a U-shaped change of decline and rise, and the overall value is relatively high. Developed provinces in the third category, such as Beijing, Shanghai and Guangzhou, have strong resilience in terms of economy, and the U-shaped trend of their economic momentum transformation is due to external economic shocks. However, the demonstration effect of their leading role still exists.

4.2. Stage cluster analysis of China's economic growth momentum transformation level

In order to better reflect the significant changes in China's economic growth momentum transition, we conducted cluster analysis on two phases: 2002–2013 and 2014–2020, with the year 2013 as the dividing point. The reason for choosing 2013 as the basis for phase division is primarily due to China's entry into the new normal of economic development, which can more comprehensively reflect the entire process of China's economic growth momentum transition [43]. After 2013, the Chinese economy has exhibited several key characteristics. First, it has shifted from high-speed growth to medium-high-speed growth. Second, there is a continuous optimization and upgrading of the economic structure, with the tertiary industry and consumer demand gradually becoming the main driving forces of economic growth. Lastly, there has been a transition from factor-driven and investment-driven growth to innovation-driven growth. The specific results are shown in Table 4.

Table 4. Stage clustering results of momentum transformation.

Category	Stage one (2002-2013)		Stage two (2014-2021)	
	Province	**Center value**	**Province**	**Center value**
The first category	Anhui, Gansu, Guangxi Zhuang Autonomous Region, Guizhou, Hebei, Heilongjiang, Hubei, Hunan, Jilin, Jiangxi, Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, Qinghai, Shanxi, Shanxi, Tibet Autonomous Region, Xinjiang Uygur Autonomous Region, Yunnan, Hainan, Henan, Sichuan, Chongqing	35.30	Anhui, Gansu, Guangxi Zhuang Autonomous Region, Guizhou, Hebei, Heilongjiang, Hubei, Hunan, Jilin, Jiangxi, Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, Qinghai, Shanxi, Shanxi, Tibet Autonomous Region, Xinjiang Uygur Autonomous Region, Yunnan, Chongqing, Liaoning	36.68
The second category	Fujian, Liaoning, Shandong, Tianjin, Zhejiang	64.50	Hainan, Fujian, Shandong.	56.58
The third category	Beijing, Guangdong, Jiangsu, Shanghai	84.79	Beijing, Guangdong, Jiangsu, Shanghai, Tianjin, Zhejiang	79.64

As can be seen from Table 4, there are stage-specific changes in the clustering characteristics of economic momentum transformation, with a tendency for the different categories to transition from lower to higher tiers. The clustering results demonstrate certain differences between the two phases, primarily reflected in two aspects: the distribution of provinces across different categories and the center values of each category. These aspects provide substantial evidence for the stage-specific changes in economic momentum transformation. Looking at the distribution of provinces across different categories, the number of provinces in the first category with lower scores decreased from 5 to 3, while the number of provinces in the third category with higher scores increased from 4 to 6. This indicates an overall transition of economic momentum from lower to higher tiers. For example, in the first phase, provinces like Hainan transitioned from the lower-scoring first tier to the higher-scoring second tier, while Tianjin and Zhejiang province from the second tier transitioned to the higher-scoring third tier. Examining the provinces in the first tier for both phases, there may be a connection between the level of economic growth momentum transition and regional economic development. However, this may not necessarily hold true for provinces in the second tier. Moreover, some provinces in the northeastern region show a reverse trend in economic momentum transformation, where the momentum index did not improve but instead declined, as observed in Liaoning, for instance. This situation may be associated with the industrial structure in the northeastern region. The northeastern region is the birthplace of China's industrial revolution and saw the rise of many important domestic enterprises, particularly in the 1980s after the founding of China, which laid the foundation for heavy industrial development in the country. The development of heavy industry made it relatively difficult to adjust the industrial structure, consequently impeding the process of momentum transformation in the northeastern region. Considering the average score of each category, the overall score of the first category has slightly increased, from 35.30 to 36.68, a percentage increase of 3.9%. The scores of categories two and three have both decreased overall, which is due to the shift of samples within the echelons and the relatively small sample size.

5. Conclusions

This paper constructed a monitoring indicator system for economic growth momentum transformation and used a comprehensive evaluation method to compile the general index and sub-indices for the four dimensions of momentum transformation. The overall index and sub-indices for provincial-level economic growth momentum transformation in mainland China were calculated, and their characteristics were analyzed, leading to the following research conclusions.

First, the level of economic growth momentum transformation in Chinese provinces exhibits phase and dimensional differentiation over time. Economic growth momentum demonstrated two significant phase features during the sample period, with the years from 2002 to 2009 being a relatively stable period for economic growth momentum transformation and the year from 2010 to 2021 being a period of significant increase. The significant phase is associated with major events. In addition, while the trends in each dimension were generally consistent, there were still certain differences between them, and the fluctuations in each dimension also exhibited some differentiation characteristics.

Second, provincial-level economic growth momentum transformation in China exhibits clustered and tiered transfer characteristics in space. Based on the sub-indices of momentum transformation, we conducted cluster analysis on the sample provinces. From the provincial clustering effect of momentum transformation, the clustering effect was mainly concentrated in the first category of provinces in Central and Western China. There is substitution demand in China's economic development and momentum transformation process, leading to phased changes in the clustering characteristics of economic momentum transformation, and different categories exhibit a trend of transfer from low to high.

Third, innovation plays an important role in the path and mechanism of economic growth momentum transformation level. Innovation is reflected in the factor dimension. From the analysis of the sub-indices for each dimension of economic growth momentum transformation, innovation has a strong correlation with factor momentum. Further analysis of the innovation index in the factor momentum shows that its weight and evolutionary trend have a very strong correlation with overall momentum transformation. In addition, from the regional clustering results, innovation also plays an important role in the path and mechanism of upgrading in each region.

Use of AI tools declaration

The authors declare they have not used artificial intelligence (AI) tools in the creation of this article.

Acknowledgments

This work was supported by the Hunan Provincial Social Science Achievement Review Committee project (XSP21YBC454).

Conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

1. F. Adedoyin, F. Bekun, O. Driha, D. Balsalobre-Lorente, The effects of air transportation, energy, ICT and FDI on economic growth in the industry 4.0 era: evidence from the United States, *Technol. Forecast. Soc.*, **160** (2020), 120297. https://doi.org/10.1016/j.techfore.2020.120297
2. F. Morina, S. Grima, The impact of pension fund assets on economic growth in transition countries, emerging economies, and developed countries, *Quant. Financ. Econ.*, **3** (2022), 459–504. https://doi.org/10.3934/QFE.2022020
3. H. Ishida, The effect of ICT development on economic growth and energy consumption in Japan, *Telemat. Inform.*, **32** (2015), 79–88. https://doi.org/10.1016/j.tele.2014.04.003
4. G. Desalegn, A. Tangl, Forecasting green financial innovation and its implications for financial performance in Ethiopian Financial Institutions: evidence from ARIMA and ARDL model, *Natl. Account. Rev.*, **2** (2022), 95–111. https://doi.org/10.3934/NAR.2022006
5. B. Muhammad, Energy consumption, CO_2 emissions and economic growth in developed, emerging and Middle East and North Africa countries, *Energy*, **179** (2019), 232–245. https://doi.org/10.1016/j.energy.2019.03.126
6. A. AI-Sarihi, J. Cherni, Assessing strengths and weaknesses of renewable energy initiatives in Oman: an analysis with strategic niche management, *Energy Transit.*, **2** (2018), 15–29. https://doi.org/10.1007/s41825-018-0008-9
7. N. Bai, C. Li, S. Du, L. Zeng, The internal logic and policy orientation of new and old momentum transformation, *Macroeconomic Manage.*, **10** (2021), 19–25. https://doi.org/10.19709/j.cnki.11-3199/f.2021.10.005
8. Z. Li, J. Zhu, J. He, The effects of digital financial inclusion on innovation and entrepreneurship: a network perspective, *Electron. Res. Arch.*, **30** (2022), 4697–4715. https://doi.org/10.3934/era.2022238
9. Y. Feng, Y. Jiang, Y. Peng, Decomposition of China's economic growth drivers: biased technological progress and factor input growth, *J. Quant. Tech. Econ.*, **9** (2017), 39–56. https://doi.org/10.13653/j.cnki.jqte.2017.09.003
10. Z. Zhu, The transformation of driving forces for China's economic growth and policy choices, *J. Quant. Tech. Econ.*, **3** (2017), 3–20. https://doi.org/10.13653/j.cnki.jqte.2017.03.001
11. Y. Xu, T. Li, Measuring digital economy in China, *Natl. Account. Rev.*, **3** (2022), 251–272. https://doi.org/10.3934/NAR.2022015
12. Z. Li, J. Zhong, Impact of economic policy uncertainty shocks on China's financial conditions, *Financ. Res. Lett.*, **35** (2020), 101303. https://doi.org/10.1016/j.frl.2019.101303
13. R. Khan, H. Arif, N. Sahar, A. Ali, M. Abbasi, The role of financial resources in SMEs' financial and environmental performance; the mediating role of green innovation, *Green Financ.*, **1** (2022), 36–53. https://doi.org/10.3934/GF.2022002
14. Z. Li, Z. Huang, Y. Su, New media environment, environmental regulation and corporate green technology innovation: evidence from China, *Energy Econ.*, **119** (2023), 106545. https://doi.org/10.1016/j.eneco.2023.106545

15. X. Xu, H. Peng, Y. Liu, The impact of heterogeneous environmental regulations on the technology innovation of urban green energy: a study based on the panel threshold model, *Green Financ.*, **1** (2022), 115–136. https://doi.org/10.3934/GF.2022006
16. X. Tian, R. Li, Empowering transformation and development of the real economy with digital technology: analysis framework based on Schumpeter's endogenous growth theory, *Manage. World*, **5** (2022), 56–74. https://doi.org/10.19744/j.cnki.11-1235/f.2022.0076
17. T. Li, J. Wen, D. Zeng, K. Liu, Has enterprise digital transformation improved the efficiency of enterprise technological innovation? A case study on Chinese listed companies, *Math. Biosci. Eng.*, **19** (2022), 12632–12654. https://doi.org/10.3934/mbe.2022590
18. Z. Li, C. Yang, Z. Huang, How does the fintech sector react to signals from central bank digital currencies? *Financ. Res. Lett.*, **50** (2022), 103308. https://doi.org/10.1016/j.frl.2022.103308
19. J. Zheng, J. Song, Y. Zhang, Y. Zheng, Q. Jiang, Progress evaluation of the transformation of new and old momentum in China's economic growth, *China Ind. Econ.*, **6** (2018), 24–42. https://doi.org/10.19581/j.cnki.ciejournal.2018.06.003
20. C. Li, R. Zhou, M. Yu, Historical evolution and regional features of new and old momentum transformation in China, *J. Quant. Tech. Econ.*, **2** (2021), 3–23. https://doi.org/10.13653/j.cnki.jqte.20210129.001
21. L. Liu, M. Liu, How does the digital economy affect industrial eco-efficiency? Empirical evidence from China, *Data Sci. Financ. Econ.*, **4** (2022), 371–390. https://doi.org/10.3934/DSFE.2022019
22. C. Li, G. Long, S. Li, Research on measurement and disequilibrium of manufacturing digital transformation: Based on the text mining data of A-share listed companies, *Data Sci. Financ. Econ.*, **3** (2023), 30–54. https://doi.org/10.3934/DSFE.2023003
23. G. Prah, Innovation and economic performance: the role of financial development, *Quant. Financ. Econ.*, **4** (2022), 696–721. https://doi.org/10.3934/QFE.2022031
24. M. Adam, Nexus among foreign direct investment, financial development, and sustainable economic growth: empirical aspects from Sudan, *Quant. Financ. Econ.*, **4** (2022), 640–657. https://doi.org/10.3934/QFE.2022028
25. Z. Li, F. Zou, B. Mo, Does mandatory CSR disclosure affect enterprise total factor productivity? *Econ. Res.-Ekonomska Istraživanja*, **35** (2022), 4902–4921. https://doi.org/10.1080/1331677X.2021.2019596
26. W. Wei, W. Cai, Y. Guo, C. Bai, L. Yang, Decoupling relationship between energy consumption and economic growth in China's provinces from the perspective of resource security, *Resour. Policy*, **68** (2020), 101693. https://doi.org/10.1016/j.resourpol.2020.101693
27. M. Liu, Q. Ma, The impact of saving rate on economic growth in Asian countries, *Natl. Account. Rev.*, **4** (2022), 412–427. https://doi.org/10.3934/NAR.2022023
28. Z. Li, B. Mo, H. Nie, Time and frequency dynamic connectedness between cryptocurrencies and financial assets in China, *Int. Rev. Econ. Financ.*, **86** (2023), 46–57. https://doi.org/10.1016/j.iref.2023.01.015
29. P. Liu, Y. Zhao, J. Zhu, C. Yang, Technological industry agglomeration, green innovation efficiency, and development quality of city cluster, *Green Financ.*, **4** (2022), 411–435. https://doi.org/10.3934/GF.2022020
30. S. Ren, H. Wu, Path to green development: the role environmental regulation and labor skill premium on green total factor energy efficiency, *Green Financ.*, **4** (2022), 387–410. https://doi.org/10.3934/GF.2022019

31. Z. Li, H. Chen, B. Mo, Can digital finance promote urban innovation? Evidence from China, *Borsa Istanb. Rev.*, **23** (2023), 285–296. https://doi.org/10.1016/j.bir.2022.10.006
32. Y. Su, Research on statistical measurement of new driving force of China's economic development and its upgrading path, *Chongqing Soc. Sci.*, **4** (2023), 35–48. https://doi.org/10.19631/j.cnki.css.2023.004.003
33. M. Radulescu, L. Serbanescu, C. Sinisi, Consumption vs. investments for stimulating economic growth and employment in the CEE countries–a panel analysis, *Econ. Res.-Ekonomska Istraživanja*, **32** (2019), 2329–2353. https://doi.org/10.1080/1331677X.2019.1642789
34. M. Rosenblatt, Remarks on some nonparametric estimates of a density function, *Ann. Math. Statist.*, **27** (1956), 832–837. https://doi.org/10.1214/aoms/1177728190
35. E. Parzen, On estimation of a probability density function and mode, *Ann. Math. Statist.*, **33** (1962), 1065–1076. https://doi.org/10.1214/aoms/1177704472
36. D. Fang, M. Pei, Study on the measurement of new and old driving force conversion and its influencing factors, *Contemp. Econ. Manage.*, **1** (2021), 26–32. https://doi.org/10.13253/j.cnki.ddjjgl.2021.01.004
37. X. Yang, X. Lu, Evolution track and influence effect of regional economic development imbalance, *Stat. Decis.*, **10** (2023), 105–110. https://doi.org/10.13546/j.cnki.tjyjc.2023.10.020
38. S. Xu, T. Chen, Analysis of the measure and mitigation path of unbalanced regional economic development in China, *Stat. Decis.*, **4** (2023), 101–106. https://doi.org/10.13546/j.cnki.tjyjc.2023.04.018
39. Z. Li, G. Liao, K. Albitar, Does corporate environmental responsibility engagement affect firm value? The mediating role of corporate innovation, *Bus. Strategy Environ.*, **3** (2020), 1045–1055. https://doi.org/10.1002/bse.2416
40. T. Li, X. Li, K. Albitar, Threshold effects of financialization on enterprise R&D innovation: a comparison research on heterogeneity, *Quant. Financ. Econ.*, **3** (2021), 496–515. https://doi.org/10.3934/QFE.2021022
41. Z. Li, L. Chen, H. Dong, What are bitcoin market reactions to its-related events? *Int. Rev. Econ. Financ.*, **73** (2021), 1–10. https://doi.org/10.1016/j.iref.2020.12.020
42. Z. Li, H. Dong, C. Floros, A. Charemis, P. Failler, Re-examining bitcoin volatility: a CAViaR-based approach, *Emerg. Mark. Financ. Tr.*, **5** (2022), 1320–1338. https://doi.org/10.1080/1540496x.2021.1873127
43. J. Zhang, J. Chen, Introduction to China's new normal economy, *J. Chin. Econ. Bus. Stud.*, **15** (2017), 1–4. https://doi.org/10.1080/14765284.2017.1289454