Multi-dimensional dynamics of income distribution, geographical disparities, and convergence among Chinese residents

Abstract

The problem of unbalanced development is an important issue facing the goal of achieving Chinese-style modernization and common prosperity. This paper employs multiple classifications and conducts a multi-time convergence study of gross domestic product per capita from 1993 to 2020 with the help of heat maps, Dagum Gini coefficient, kernel density estimation, and Markov chains . We forecast and analyze the distribution dynamics, regional differences, and convergence using long short term memory. The results suggest that LSTM's forecasting potential is better than the gray forecasting method, and the national and regional residents' incomes will show obvious convergence from 1993 to 2035, among which the east and northeast regions will show club convergence. The absolute difference of residents' incomes will shrink, and the polarization phenomenon will diminish. Inter-regional differences will be the main source of disparities, and the residents' income level will be stable, with a higher probability of upward development.

Keywords: common prosperity; heat map; long short term memory; convergence; distribution dynamics; regional differences

JEL codes:E27,O11,P24,R11

I. Introduction

In a report of the 20th National Congress of the Communist Party of China, it was pointed out that the problems of unbalanced and insufficient development in China are still severe, and the mission and tasks of the new era and new journey should emphasize that "Chinese modernization is the modernization of common prosperity for all people," and it should "firmly prevent polarization." Since the new era, China's economic development has been in line with international standards, and the domestic and

international environment has continued to undergo profound changes. Due to the vast size of China and the different resource endowments and development policies of each province, there are complex differences in economic development, especially in the income levels of residents across regions (Lin and Liu, 2003; Pan, 2010; Dong and Chi, 2020). As China's economy enters a new normal of medium- to high-speed growth, the problem has been presented as a typical regional clustering distribution in the four major sectors. As examples, the eastern region has shown obvious medium- to high-speed development; the northeastern region has shown economic downside risks under multiple pressures, such as industrial structure imbalance; and most provinces in the middle and western regions have shown high-speed development due to the economic dividends of investment expansion. The goal of the new era and new journey makes it necessary to accomplish coordinated regional development with high quality, which requires us to objectively depict and elaborate the current situation of common prosperity development in China's regions and especially the differences in and convergence of residents' income levels. It is also imperative to analyze the causes of regional economic development differences and lay the foundation for the realization of socialist modernization by 2035.

The remainder of this paper is organized as follows. Part II introduces the origin of the study and reviews the existing studies. Part III briefly presents the relevant convergence models, such as absolute β-convergence and Dagum Gini coefficient decomposition. It also compares the forecasting results of the gray forecasting method and long short term memory (LSTM). Part IV reports the convergence of resident income levels during the historical examination period and after adding the forecasts as well as the distribution dynamics and other characteristics and trends. Part V presents the conclusions and implications.

II. Review of Literature

1. Theoretical origin of convergence research

The domestic research on common prosperity focuses on the differences and

convergence of economic development, which is also a topic of attention in domestic and foreign economic growth theories. The economic convergence model originated from Solow (1956), and it proposed that if all economies have the same population growth rate, savings rate, and other variables, each economy will converge to the same steady-state value, i.e., absolute convergence. Later, Barro & Sala-I-Martin (1992) established a cross-sectional regression model under the framework of neoclassical growth model for the contiguous 48 US states and 98 OECD countries. Since then, many scholars have used the beta convergence model to evaluate the convergence of national or regional economies. Foreign scholars have also studied specific elements, such as the effect of convergence on economic welfare (Baumol, 1986), factors limiting economic convergence (Mankiw et al., 1992), exploration of convergence from an economics school perspective (Sala-i-Martin, 1996), long-term stability issues of convergence (Andrew et al., 2012), exploration of conditional convergence and club convergence (Enrico et al., 2019), and integration of machine learning into convergence studies (Magazzino et al., 2022).

2. Economic convergence in China

Have region-wide convergence and club convergence been prevalent in China in previous years, and what are the future trends? There is rich literature on the study of convergence in China, but the findings vary for different observation periods and regional divisions. For example, some scholars have supported the existence of region-wide convergence in China (Wei-Min Yang, 1992; Xue-Min Song, 1996; Wen-Qing Pan, 2010); some scholars have argued that region-wide convergence is stage-specific (Hou-Kai Wei, 1997; Sheng Zhang et al. 2001; Dong and Chi 2020); and some scholars have concluded that there is no overall convergence (Shen and Ma, 2002; Wang Zheng and Ge, 2002). Studies on club convergence also vary due to the differences in observation periods and regional divisions, with some literature supporting the prevalence of club convergence (Lin and Liu, 2003; Wang, 2004) and others arguing that there is only local club convergence (Chen and Li, 2004; Peng, 2005;

Zhu, et al. 2014). There are also many scholars who do not limit the convergence analysis to GDP per capita or income per capita but use other indicators or models to study the convergence and differences of economic development. They also expand the scope of the study of economic convergence, such as comparing the convergence of China with that of other countries (Qi et al., 2009), using other indicators or constructing indicator systems (Suji and Xu, 2015; Deng et al. 2020; Lan et al. 2021), and studying the characteristics of convergence and the dynamic distribution of economic development with the help of methods such as kernel density estimation and the Dagum Gini coefficient decomposition method (Chen Jinghua et al. 2020; Zhao and Zhang 2022; Tong et al. 2022).

3. Future convergence of China's economy

Will the future convergence of China be similar to its history? There is a large amount of literature related to forecasting and studying China's future economy with a wide range of methods and scopes, such as using gray forecasting, expert forecasting, and machine learning to forecast economic variables, such as GDP for the whole country or individual regions (Wang et al., 2017; Liang et al., 2017). There are also studies using scenario analysis and econometric methods to forecast economic development (Wang, 2014; Zhang and Su, 2020). Based on the above research, the following hypotheses are proposed in this paper.

Hypothesis 1: The convergence of China's resident income exists in the long run, and its existence in the short run is related to the examination period.

Hypothesis 2: The regional differences in Chinese residents' income show an overall trend of narrowing.

Hypothesis 3: The dynamics of income distribution in China tend to converge.

Hypothesis 4: The transfer characteristics of Chinese residents' income are stable.

In summary, the existing literature mainly focuses on convergence studies for China as a whole or for a single time period in the region, without an overall analysis through multiple time periods, which leads to widely different conclusions. The existing

convergence studies have been conducted on historical data, and most of them use a single model or two models to examine the dynamic distribution, regional differences, transfer characteristics, and convergence of residential income levels. In view of this, this paper attempts to make marginal contributions in the following aspects: (1) to portray multi-temporal convergence with a more scientific and intuitive convergence heat map; to dismantle, arrange, and combine a single time period into numerous time periods; and to comprehensively display and analyze the convergence and differences of different time ranges with the help of features such as the comparison of the number of convergence and divergence points, the depth of color, and the degree of aggregation; (2) to systematically study the income level of residents with the help of multiple methods, such as a convergence model, the Dagum Gini coefficient decomposition, kernel density estimation, and Markov chain; (3) to apply an LSTM network to predict the income level of residents at a particular time point in 2035 and explore its distribution dynamics, regional differences, and convergence; expand the scope of application of convergence and divergence; combine and compare the historical characteristics from 1993 to 2020; and propose policy recommendations for the basic realization of socialist modernization and realization of common prosperity by 2035.

III. Research Methodology and Data Description

1. Research methodology

This paper aims to observe the convergence, distribution dynamics, and regional differences of the overall and regional income levels in China from different perspectives, such as north–south regions, four major sectors, and K-means. This paper also conducts systematic and comprehensive analysis with the help of convergence models, heat maps, Dagum Gini coefficient decomposition, kernel density estimation, and Markov chains. The forecasting potentials of the gray forecasting method and LSTM with a gating mechanism are compared, and we evaluate and select the best performer by combining waterfall diagrams and multiple indicators to forecast GDP per capita from 2021 to 2035 and analyze what trends and characteristics our country can

adopt to meet the target time point of 2035.

(1) Convergence model

Absolute β-convergence. According to neoclassical growth theory, all else being equal, poor regions will grow faster than rich regions. This paper draws on previous studies to measure the beta convergence coefficient of regional economic growth to test absolute beta convergence with the following equation:

$$\frac{ln(y_{i,t+T}/y_{i,t})}{T} = \alpha_0 + \beta_0 ln y_{i,t} + \varepsilon_{i,t} \quad (1)$$

where α_0 is the constant term; $ln(y_{i,t+T}/y_{i,t})/T$ is the GDP per capita growth rate of province i from the initial period t to period t+T; $y_{i,t+T}$ is the GDP per capita of province i in period t+T; $\beta_0$is the convergence coefficient; and $\varepsilon_{i,t}$ is the disturbance term. If the estimated value of β_0 is less than 0, this indicates that there is absolute convergence; that is, the backward regions grow faster than the rich regions. The opposite does not indicate convergence.

Heat map. In the existing literature, convergence analysis is mainly performed for one or several observation periods; so, the conclusions often have large differences. To improve the analysis of convergence, this paper refers to Patel et al. (2020) to draw an absolute beta convergence heat map, which is more intuitive and effective for showing the convergence of GDP per capita over different time spans. In the map, both the horizontal and vertical axes represent years, and each dot represents the coefficient β_0 of equation (1), with the specific meaning of its horizontal coordinate as t+T and vertical coordinate as the convergence obtained in the initial period t coefficients. The positive red indicates divergence, and negative blue indicates convergence, and the color shades indicate the absolute size of the beta values. Figure 1 shows the absolute beta convergence heat map of China from 1993 to 2020. Its y-axis indicates the range of the initial years, and the x-axis indicates the range of the final years. The β_0 convergence corresponding to each time period from 1993 to 2020 can be shown comprehensively by the 378 points in the figure, compared with the single time period

analyzed or visualized in the existing literature. Moreover, compared with the previous studies on a single time period, the heat map can help analyze the convergence, distribution differences, and regional characteristics of the whole country and each region more comprehensively and effectively with the help of its features such as the comparison of the number of red dots and blue dots, the depth of color, and the degree of aggregation.

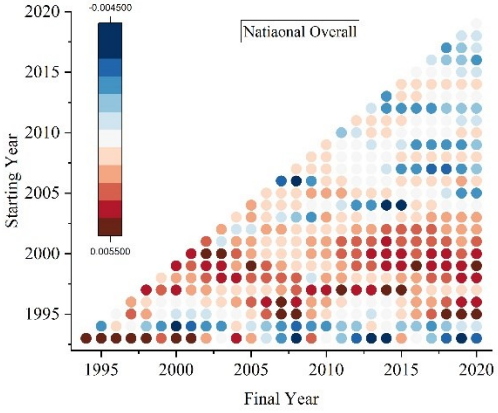


Fig. 1 Example of an absolute β-convergence heat map

(2) Dagum Gini coefficient decomposition

The Gini coefficient and decomposition method proposed by Dagum (1997) is used to determine the regional differences and sources of residential income levels. The total Gini coefficient is divided into the intra-regional contribution G_w, inter-regional contribution G_{nb}, and super-variable density contribution G_t.

(3) Kernel density estimation

We use kernel density to estimate the distribution location, pattern, and extension of economic development nationally using three classification methods. The economic development probability function of each province is assumed to be f(x), calculated as follows:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K(\frac{X_i - \bar{x}}{h}) \quad (2)$$

where N denotes the number of observations; $X_i$denotes the independent identically distributed observations; $\bar{x}$ denotes the mean of the observations; and h denotes the bandwidth. A Gaussian kernel density function is used to estimate the dynamic distribution of economic development in each region.

(4) Markov chain transfer matrix

To reflect the internal flow direction of the income level of residents and its location transfer characteristics, this paper introduces the Markov transfer probability matrix for analysis. We refer to Chen and Qing (2022) and Tong et al. (2022) to adopt the quadratic approach for grading and classify the national GDP per capita of all provinces involved in the period from 1993 to 2020 into four levels: low level, medium-low level, medium-high level, and high level. The final Markov transfer probability matrix can be calculated as follows:

$$B(n) = \begin{bmatrix} b_{\alpha-\alpha}(n) & b_{\alpha-\beta}(n) & b_{\alpha-\gamma}(n) & b_{\alpha-\delta}(n) \\ b_{\beta-\alpha}(n) & b_{\beta-\beta}(n) & b_{\beta-\gamma}(n) & b_{\beta-\delta}(n) \\ b_{\gamma-\alpha}(n) & b_{\gamma-\beta}(n) & b_{\gamma-\gamma}(n) & b_{\gamma-\delta}(n) \\ b_{\delta-\alpha}(n) & b_{\delta-\beta}(n) & b_{\delta-\gamma}(n) & b_{\delta-\delta}(n) \end{bmatrix} \quad (3)$$

The elements on the main diagonal represent the retention probability, which indicates the probability that the weight of the four classes remains constant. The elements outside the main diagonal represent the transfer probability, which indicates the probability that the class is transferred to other classes.

(5) Gray prediction method

The gray forecasting model can process discrete data into data with strong regularity, construct continuous differential equations, and determine the parameters in the equations through mathematical methods to make forecasts. We use the cumulative method to build a GM (1, 1) model to predict the future GDP per capita of each

province. The accuracy level of the gray prediction model is presented in Table 1. Passing the four-level accuracy test indicates that the test is qualified. We refer to the relative error test standard selected by Feng, Mei and Chen, Peng (2013).

(6)LSTM network

LSTM neural networks were first proposed by Hochreiter & Schmidhuber (1997). They have been used to predict time series data due to their excellent ability to process time series data and their higher prediction accuracy compared to other models (Choi & Lee, 2018; Ouyang et al., 2020).

The LSTM neural network model mimics the artificial neural network. It uses multilayer linear weighted summation and nonlinear activation function nesting to capture information about the data. LSTM adds a gating mechanism to the RNN model to better learn the long-term relationships in the data. Generally, the changes in China's economic development will not only be influenced by the recent past but also by any period in the past. However, the more distant the past time point is from the present, the less impact it may have. Accordingly, LSTM can help more fully absorb the information of GDP per capita of each province from 1993 to 2020, filter out the redundant information, and make effective forecasts. This paper draws on previous literature (Grave, 2012; Hu et al., 2022) to construct a schematic diagram of the LSTM framework, as shown in Figure 2, where X_t is the information of the parameters newly passed into the training process; h_{t-1} denotes the stage results of the previous iteration; the forgetting gate filters the information entering the activation function in h_{t-1}; C_{t-1} and C_t are the information of the previous period; and the role of the update gate is to update this state. Finally, the output is provided by the output gate control. The prediction model can be improved by correcting the error through several iterations.

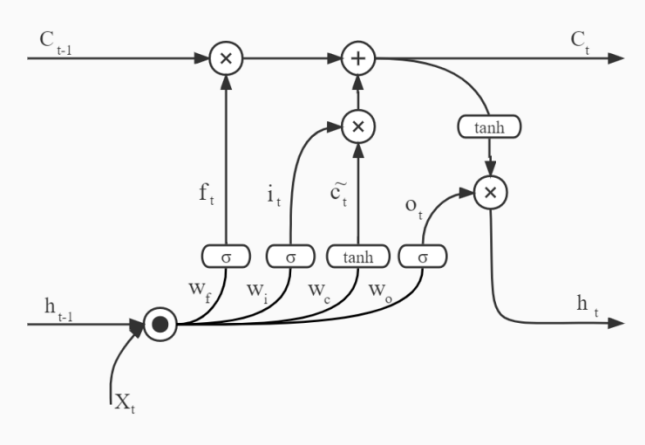


Fig. 2 Schematic diagram of the long short term memory (LSTM) network framework

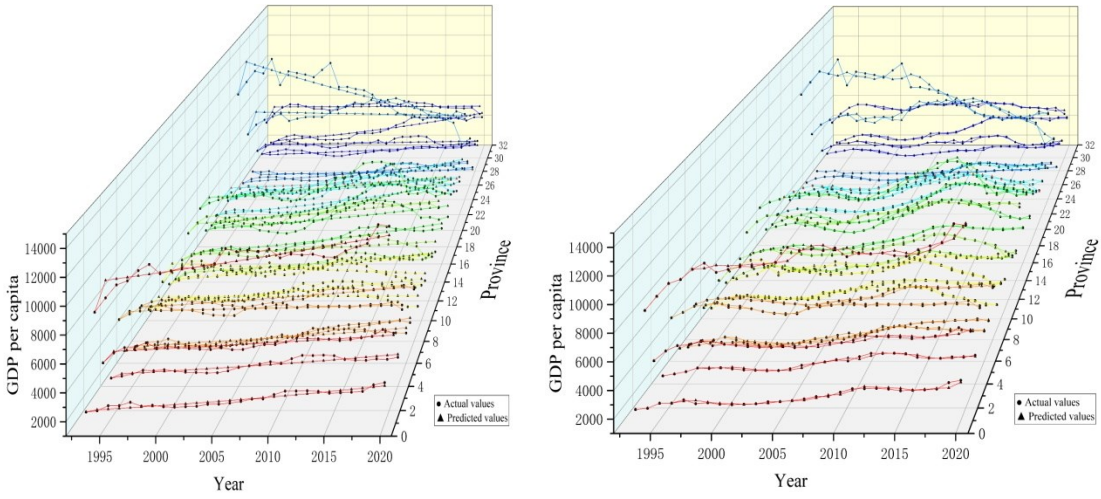
For a rigorous comparison of the predictive ability, this paper uses the mean square error (MSE), root mean square error (RMSE), mean absolute percentage error (MAPE), and symmetric mean percentage error (SMAPE) as measures of the out-of-sample predictive ability of the gray prediction method and the LSTM model, with reference to relevant studies such as Yang and Wang (2019) and Xiao et al. (2020).

2. Data description

We use GDP per capita to characterize the level of residents' income. The data are mainly obtained from the China Statistical Yearbook, with 1993 as the base period for deflating and some missing data supplemented from the statistical yearbooks of each province. To observe from multiple classifications, this paper draws on Dong and Chi (2020) and Tong et al. (2022) to examine the economic convergence of China overall across four major sectors and the north–south regions, respectively. We use K-means classification to study the overall and regional economic convergence of China through another perspective. The final results of the three classification divisions are shown in Table A.1. in the appendix.

Prediction results: This paper uses the combined waterfall plot to compare the forecasting potential of the gray forecasting method with that of the LSTM network. From Figure 3a, we can see that the gray prediction method only captures the roughly linear trend of the change of GDP per capita, and there are many provinces with larger

climbs and declines that are not well-portrayed, indicating that the optimization of the model has more room for improvement. It can be seen from Figure 4b that compared with the gray prediction method, the LSTM network not only captures the roughly linear trend but also absorbs the previous information and captures the nonlinear relationship. The four performance comparison indicators show that the LSTM network's forecasts for all provinces produce lower measured results for all four indicators than the gray forecasting method (see Figure A.2. in the appendix). In summary, this paper chooses LSTM to forecast the GDP per capita of each province from 2021 to 2035 and explore its convergence, regional differences, distribution dynamics, and transfer characteristics.



(a) Gray forecasting method (b) Long short term memory

Fig. 3 Waterfall plot of out-of-sample actual and true values grouped by province

IV. Empirical Results and Analysis

1. Convergence analysis of China's history and future

In Figure 4, the heat map shows the overall absolute β-convergence of China from 1993 to 2035, where the convergence of the historical dimension from 1993 to 2020 is shown in the left part of the heat triangle and the convergence of the forecast data is shown in the right part of the heat triangle. In the overall national observation, if the earlier years are used as the base period, there is divergence. If the other years are used as the base

period, the trend is convergence, but the convergence intensity is smaller. The blue β coefficients indicating convergence in the historical period are concentrated in the middle and above the thermal triangle, indicating that if the years in the range of 2002–2019 are taken as the starting years and either the approaching or distant years are taken as the end years, the blue dots representing convergence are continuous but lighter in color, indicating that if the absolute β-convergence is calculated for that time range, the conclusion is basically convergence but with lower convergence intensity. If we take the years from 1993 to 2001 as the starting years, the blue convergence points are fewer and the red divergence points are concentrated in patches, which means that the absolute β-convergence in this time range is basically divergence and the intensity of divergence is not low. The heat map after adding the prediction data is more similar to the previous one, showing that the earlier years as the starting years show divergence and the intensity is not low, and with the other years as the base period, the trend is convergence. The heat map is similar to the previous one, which shows that when the earlier years are the starting years, the intensity is not low.

From the overall analysis of the country, compared with the end of the 20th century, both the current and 2035 time points show a divergence trend. Compared with the beginning of the 21st century or the decade, the country shows a typical convergence trend, which is closer to the reality. After the 1992 South Talks, due to the advantages of location and policy reform, the middle and eastern coastal regions boomed. The western regions have been catching up but always lagging. After entering the 21st century, especially after the 17th National Congress, the Party has put more emphasis on common prosperity, and policies related to urban–rural coordination and rural revitalization have been well implemented. Therefore, although the gap between regions still exists, the economic development of the originally backward regions has shown a growth rate that exceeds that of the originally more-developed regions, thus leading to a convergence trend. From the analysis of the forecast data, compared with the beginning of the 21st century, we find that the country will develop in a converging trend, and the

regional disparity in China will continue to narrow by 2035, and China will be one step closer to the goal of common prosperity.

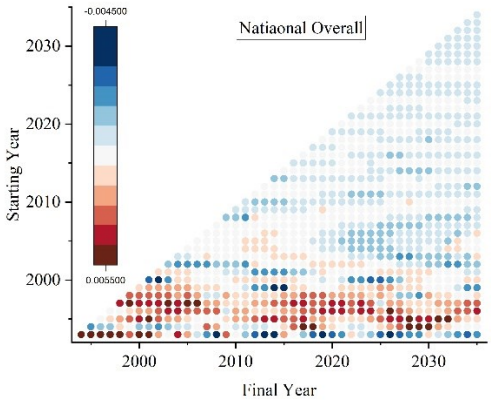
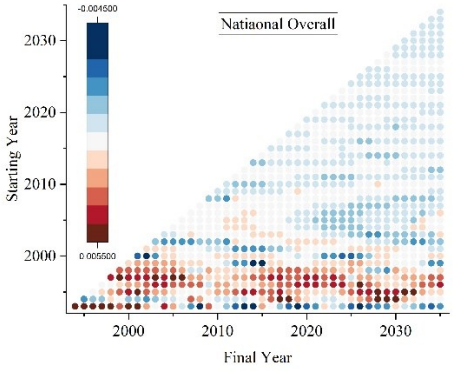


Fig. 4 Absolute beta convergence heat map of China from 1993 to 2035

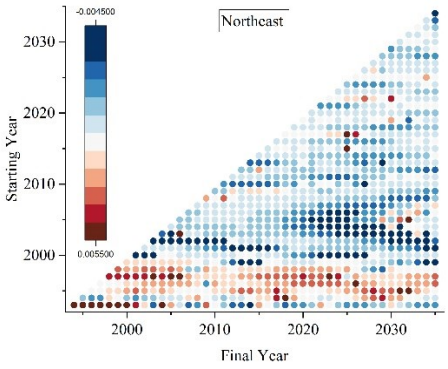
For the classification based on the four major sectors, the convergence of each of the four major regions has their own characteristics. The east's and northeast's convergence is similar, showing divergence compared to earlier years. Using the other years as the starting years shows convergence, where the convergence intensity of the northeast is higher than that of the east. The middle's and west's convergence is similar, showing divergence in a wider range of years than the east and northeast, where the intensity of the west is higher than that of the middle, again indicating club convergence. The existence of convergence is shown in detail in Figure 5. The comparison reveals that the blue β coefficients indicating convergence in the historical periods of both the east and northeast are concentrated in the middle and in most of the area above the thermal triangle, and if the years in the range of 1999–2019 are taken as the starting years, and the approaching or distant years are taken as the end years, the patches of converging blue dots strongly show the convergence of the two regions, with the northeast converging in a darker color. This indicates that the heat map after adding the forecast data shows a more obvious convergence trend, and the blue convergence points occupy a larger area. If the range of the starting years for the convergence conclusion is expanded to 1999–2035, the convergence intensity of the northeast is still higher than

that of the east. The blue β coefficients indicating convergence in the historical periods of the middle and west are concentrated above the thermal triangle. If the years in the range of 2009–2019 are taken as the starting years, and the approaching or distant years are taken as the end years, the more intensive convergence blue points better illustrate the convergence of the two regions, and the convergence color of the west is slightly darker.

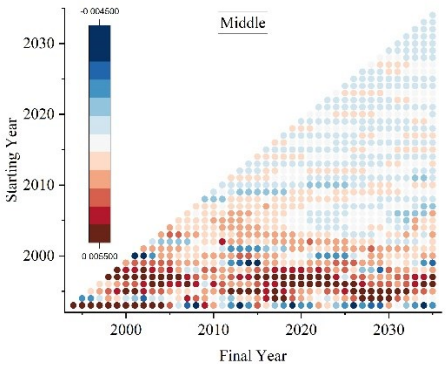
The heat map after adding the forecast data shows a more obvious convergence trend. If the range of the starting years for the convergence conclusion is expanded to 2009–2035, the convergence intensity in the west is still higher than that at the center. In summary, the empirical results support Hypothesis 1, i.e., income convergence exists in the long run for Chinese residents and its existence in the short run is related to the examination period.



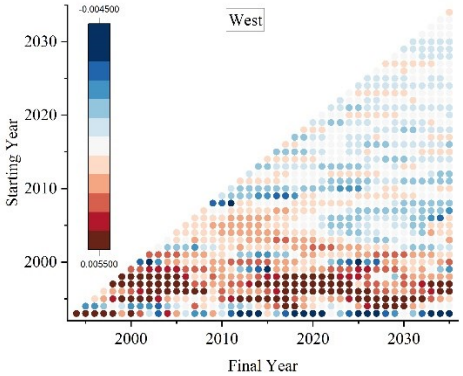
(a) East heat map



(b) Northeast heat map



(c) Middle heat map



(d) West heat map

Fig. 5 Heat map of the absolute beta convergence in the four major sectors from 1993 to 2035

2. Regional differences in China's per capita income and their decomposition

The results measured for the four major sectors are shown in Figures 6–8. The regional differences in the income levels of the Chinese sectors narrowed between 1993 and 2020. The overall Gini coefficient fluctuated and decreased, with only a few years showing an increase. There was a decrease from 0.2973 in 1993 to 0.2038, which is a decrease of 31.45%. The overall period from 1993 to 2035 showed a fluctuating decrease, from 0.2973 in 1993 to 0.2081, which is a decrease of 30.02%. In addition, a decrease of 30.02%, from 0.2973 to 0.2081, indicated that the regional differences in the residents' income levels were moving toward 2035 with a decreasing trend.

Intra-regional differences: During the historical period, the intra-regional differences in the four major sectors were large, with the largest intra-regional differences in the east and the smallest in the middle. In general, the intra-regional differences in the four major sectors decreased, except for the northeast, which showed a club convergence trend. The intra-regional variation in the eastern region declined and then increased, with a mean value of 0.2158. It decreased 2.64% from 0.2351 in 1993 to 0.2289 in 2035. The intra-regional variation in the western region increased and then decreased 3.90% from 0.1162 in 1993 to 0.1117 in 2035. The intra-regional variation in the northeast region increased 12.00% from 0.1301 in 1993 to 0.1466. The differences in the middle region were small and showed a steady decline, with a mean value of only 0.006. They decreased 39.37% from 0.0594 in 1993 to 0.0360. After combining the forecast data as a whole, the differences in the four major sectors were large and fluctuating, with the largest differences in the eastern region and the smallest in the middle region The eastern and middle regions showed a club convergence trend. The difference within the eastern region first decreased and then increased; its average value was 0.2158. It fell 17.87% from 0.2351 in 1993 to 0.1931. The difference within the western region increased and then decreased. From 0.1162 in 1993, it rose 12.32% to

0.1305. The difference within the northeast region increased, from 0.1301 in 1993 to 0.1344. The difference in the middle region was very small and showed a steady decreasing trend, with a mean value of only 0.006. It dropped 23.97% from 0.0594 in 1993 to 0.0452.

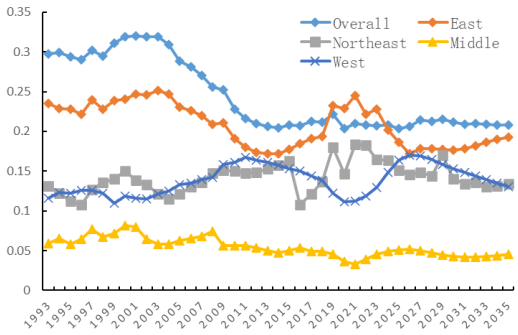


Fig. 6 Overall differences and intra-regional differences among the four major sectors

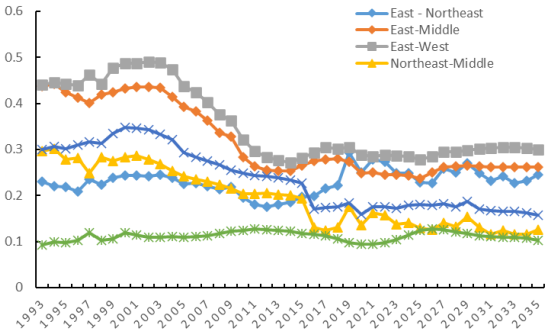


Fig. 7 Inter-regional differences among the four major sectors

Inter-regional differences: Overall, the inter-regional differences among the four major regions showed a fluctuating decline in the historical examination period, and the income level of the residents tended to be coordinated. The inter-regional differences between the eastern region and the middle and western regions were larger, and the downward trend was obvious, with the inter-regional differences between the east–middle and east–west decreasing by 41.79% and 34.73%, respectively, and the inter-regional differences between the east–northeast decreasing and then increasing by 8.92%. The inter-regional differences between the northeast–middle and northeast–west showed a fluctuating decrease of 54.08% and 47.26%, respectively. The inter-regional difference was smaller in the middle–west. Its average value was only 0.1116, but it increased by 0.96% from 0.0932 in 1993 to 0.0941. For 1993–2035 as a whole, the difference between regions basically showed a fluctuating decline, and the income level of the residents tended to be coordinated. After adding the forecast data as a whole, the difference between the eastern region and the middle and western regions was larger, but the downward trend was obvious, down by 40.06% and 31.83%, respectively. The difference between the east–northeast region first decreased and then increased, up by

6.49%. The difference between the northeast–middle and northeast–west showed a fluctuating decline, down by 57.37% and 47.82%, respectively. The smallest difference between regions was in the middle–west; its average value was only 0.1116, but it increased by 0.96% from 0.0932 in 1993 to 00941. Overall, the income level of the residents between the regions tended to be coordinated.

Sources and contribution of regional differences: The contribution of inter-regional differences was the largest during the historical examination period. The variation range was from 61.53% to 79.65%, with an average contribution of 72.95%. The contribution of intra-regional differences varied from 17.36% to 23.52%, with an average contribution of 19.82%, indicating that compared with inter-regional differences, the contribution of intra-regional differences was smaller and was not the main cause of the regional differences. For the inter-regional hypervariable density, the contribution range was from 2.77% to 15.43%, with an average contribution of 7.23%, indicating that the inter-regional sample cross-over problem had less impact on the coordinated regional economic development. After adding the forecast data as a whole, the contribution of inter-regional variation in the four major sectors was the largest, with the variation range being 60.20%–79.65%, with an average contribution of 70.40%. The contribution of intra-regional variation was between 17.36% and 24.31%, with an average contribution of 20.83%, indicating that the contribution of intra-regional variation was small compared with that of inter-regional variation and was not the main cause of regional variation. The contribution of inter-regional hypervariable density was from 2.77% to 15.59%, with an average contribution of 8.77%, indicating that the cross-over problem of the inter-regional sample had little impact on the coordinated regional economic development, leading to the inference that the focus of solving the problem of regional differences in the four major sectors should be to reduce the intra-regional differences in the four major regions. In summary, the empirical results support Hypothesis 2, i.e., regional differences in Chinese residents' income show an overall trend of narrowing.

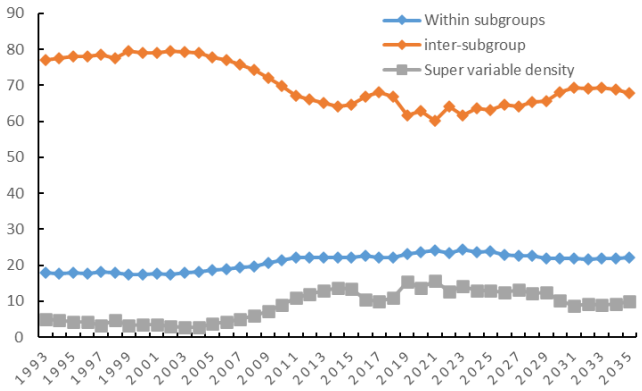


Fig. 8 Sources of overall differences in the income levels of the residents in the four major sectors

3. Dynamic evolution of the distribution of per capita income in China

In Figure 9, during 1993–2020, the position of the main peak of the distribution curve of China's residents' income level shows a "right-shift-left-shift-right-shift." The height decreases and the width remains about the same; the number of side peaks gradually decreases; and the right trailing tail always exists but narrows in extension. In general, the unevenness of regional development nationwide is narrowing, and the overall development is converging. After adding the data from 2021 to 2035, the position of the main peak of the distribution curve of the national residents' income level from 1993 to 2035 shows a "right-shift-left-shift-right-shift-left-shift." The height fluctuates; the width widens; the number of side peaks gradually decreases and approaches the main peak; and the right trailing tail always exists but narrows. This indicates that the unevenness of development is narrowing nationwide, and the overall trend is convergence.

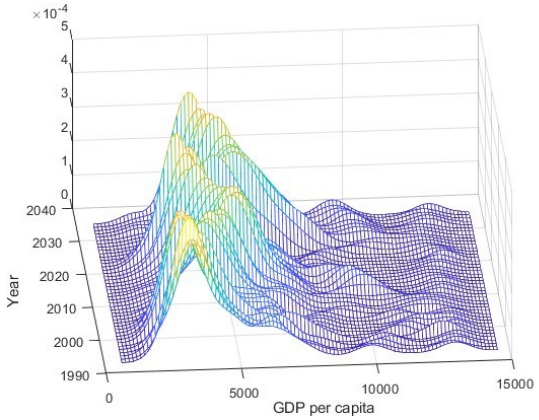
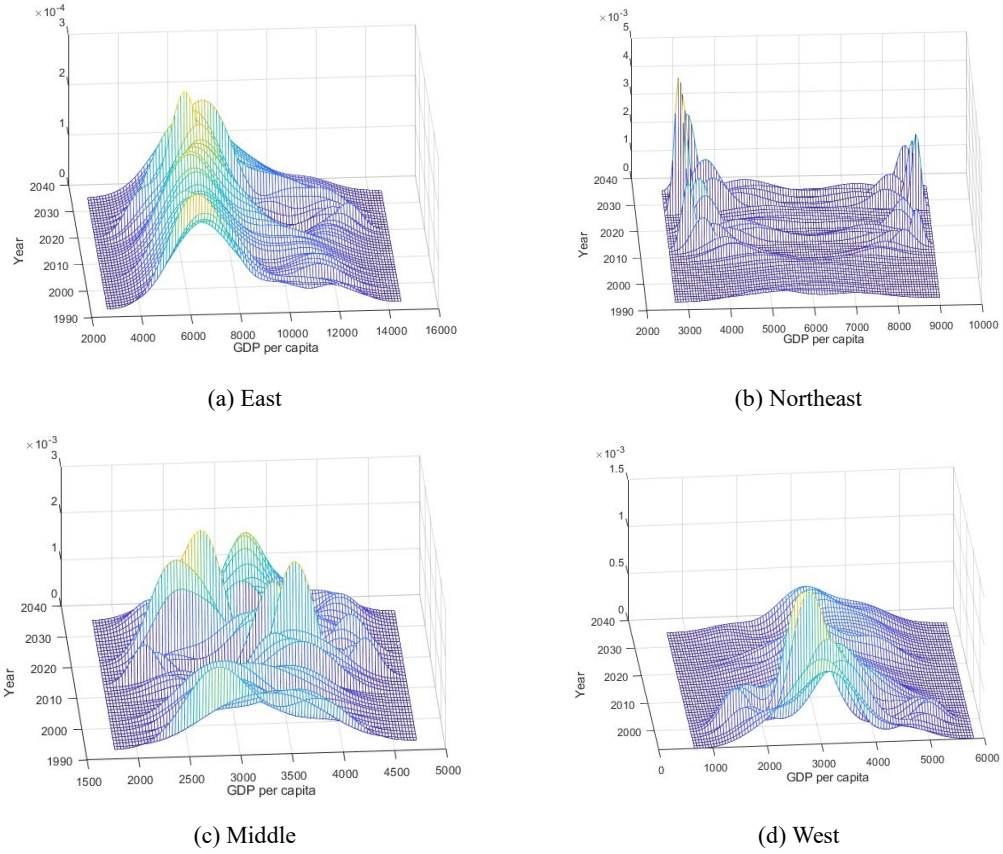


Fig. 9 Dynamics of the distribution of income levels in the country from 1993 to 2035

Classification based on the four major sectors: In Figure 10, the position of the main peak of the eastern distribution curve as a whole remains unchanged; the height fluctuates downward, while the width fluctuates and becomes narrower; the side peaks gradually disappear; and the right trailing tail always exists, while the ductility first widens and then narrows, indicating that the eastern part as a whole presents a convergence trend. The main peaks of the northeast distribution curve diverge from a single center to both sides, and the height fluctuations of the main peaks on both sides increase, but the width fluctuations narrow, indicating that there is polarization, but the absolute difference shows a trend of first widening and then narrowing. The position of the main peak of the middle distribution curve shifts to the right and then to the left; the height fluctuation increases, while the width fluctuation narrows; the side peaks first disappear and then reappear and finally nearly disappear; the image as a whole first becomes a right trailing tail to a left trailing tail and finally reverts to a right trailing tail; and the extension fluctuation narrows, indicating that the middle part as a whole shows a convergence trend. In the western region of the distribution curve, the position of the main peak is shifted to the right; the height fluctuation decreases, and the width fluctuation narrows, except for the early years; there is basically no side peak; and the image as a whole first shows a left trailing tail and then becomes a right trailing tail; and the extension fluctuation widens, indicating that the overall trend is convergence. The dynamic distribution characteristics are shown in Table 1.

In summary, the empirical results support Hypothesis 3, i.e., the dynamics of the distribution of Chinese residents' income tend to converge.



(a) East (b) Northeast

(c) Middle (d) West

Fig. 10 Distribution dynamics of the income levels of the residents in the four major sectors

Table 1

Evolutionary characteristics of the dynamics of the distribution of the income levels of the residents nationwide and by region from 1993 to 2035

Region	Main peak distribution trend		Distribution ductility		Polarization
	Peak	Width	Trailing	Ductility	
National	Constant	Broaden	Right	Narrowing	None
East	Decline	Narrowing	Right	Narrowing	None
Northeast	Constant	Narrowing	Bimodal distribution		Yes
Middle	Rise	Narrowing	Right	Narrowing	None
West	Decline	Narrowing	Right	Broaden	None

4. Dynamic transfer analysis of the per capita income of Chinese residents

This paper uses Markov chains to analyze the transfer characteristics of the per capita income's historical and forecast data (Table 2). Taking the period from 1993 to 2035, the diagonal probability of the transfer matrix of the whole country and each region is greater than the non-diagonal probability, which indicates that the income level of the residents of the whole country and each region will continue to be stable, and there is a club convergence phenomenon. There is a general transfer between adjacent types, such as the low-level rises to the middle and low level, and the middle-level and high-level fall to the middle level. There are only a few cross-type transfers. However, the overall probability of rising is higher than the probability of falling, indicating that the overall and regional income levels in China will continue to show a "multi-directional changes but mainly rising" trend in the future, and there is a risk of falling, but the probability of upward development is higher than the probability of downward development.

For the overall national perspective, on the way to 2035, the diagonal elements are always larger than the non-diagonal elements, and there is a club convergence phenomenon. The probability of maintaining the original rank in the high-level provinces is relatively high, which indicates that the club convergence phenomenon will be more obvious in the future compared with the other levels. The rank-shift occurs in the adjacent types and "jumps." The probability of moving up one level after one year is 9.39%, 10.59%, and 3.99% for the low, medium-low, and medium-high levels, respectively, which shows that the development of residents' income level is diversified during the period under study, and the development trend of the different levels is different. The probability of downward shift of the low, medium, and high levels is 4.05%, 7.06%, and 2.15%, respectively, and the probability of leaping from the medium to low levels is 0.31%, indicating that there is a risk of decline, but the probability of upward development is higher than the probability of downward development.

If we classify the four major sectors, from the main diagonal, the elements on the main diagonal of the four major sectors are larger than the elements on the non-diagonal,

which indicates that there is club convergence. Compared with the other levels, the convergence of the high-level clubs in the four major sectors is more obvious, and high-level club convergence is more evident in the east, central, and west regions, whereas low- and high-level clubs in the northeast club have a more pronounced convergence. The probability of upward shift in the northeast and west is greater than the probability of downward shift, and the probability of downward shift in the northeast and middle is similar to the probability of upward shift. This shows that there is a risk of downward shift in the four major sectors in the future, but the probability is not higher than the probability of upward shift overall.

In summary, the empirical results support Hypothesis 4, which states that the transfer characteristics of Chinese residents' income are stable.

Table 2

Markov shift probability matrix for the country and regions from 1993 to 2035

Region	Type	Low	Medium-low	Medium-high	High
National	Low	0.9061	0.0939	0.0000	0.0000
	Medium-low	0.0405	0.8536	0.1059	0.0000
	Medium-high	0.0031	0.0706	0.8865	0.0399
	High	0.0000	0.0031	0.0215	0.9754
East	Low	0.9151	0.0755	0.0094	0.0000
	Medium-low	0.0481	0.8462	0.1058	0.0000
	Medium-high	0.0000	0.0857	0.8857	0.0286
	High	0.0000	0.0000	0.0190	0.9810
Northeast	Low	0.7500	0.2500	0.0000	0.0000
	Medium-low	0.2258	0.6774	0.0968	0.0000
	Medium-high	0.0000	0.0938	0.8125	0.0938
	High	0.0000	0.0000	0.0645	0.9355
Middle	Low	0.8769	0.1231	0.0000	0.0000
	Medium-low	0.0317	0.8095	0.0952	0.0635

	Medium-high	0.0000	0.0820	0.8361	0.0820
	High	0.0000	0.0000	0.1111	0.8889
West	Low	0.8594	0.1406	0.0000	0.0000
	Medium-low	0.0709	0.8268	0.1024	0.0000
	Medium-high	0.0000	0.0323	0.9113	0.0565
	High	0.0000	0.0000	0.0240	0.9760

5. Robustness tests

(1) Different regional definitions

As mentioned in the previous section, the phenomenon of club convergence will continue to exist in China, both for the country as a whole and for the four major sectors, with regional differences gradually decreasing and the probability of upward shifts being greater than downward shifts. There will be a convergence trend toward the target time point of 2035. Due to the specificity of dividing the sample according to four major sectors, the analysis of the convergence of the per capita income, regional differences, distribution dynamics, and transfer characteristics may be biased. To mitigate the biasing of the analysis conclusions caused by a single division, this paper tests the classifications of north–south and by K-means and re-calculates and analyzes the results. The conclusions remain essentially the same (see Figures A.3–5 and Table A.2–3 in the appendix).

β-convergence with heat map. For the classification north–south, the convergence of south–north is similar, and the convergence intensity of the north is higher than that of the south, showing certain characteristics of club convergence. Compared with the early 21st century, we found that south–north will continue to develop with the trend of convergence, and the gap within the south–north region will continue to narrow in the future. Classification by K-means provides similar results as the classification by north–south and by the four major sectors. It shows club convergence, which also indicates that the K-means classification has support and reference significance for

convergence analysis, especially club convergence. Both divisions will continue to develop with a convergence trend, with the first division being more obvious.

Dagum Gini coefficient and decomposition: Overall, there was a volatile decline in the north–south classification, which indicates that the regional differences in residents' income levels are moving toward 2035 with a decreasing trend. The overall intra-regional gap decreases and shows a club convergence trend. The intra-regional differences between the south and north show a fluctuating decrease, and the inter-regional differences between the south and north fluctuate and decrease. The contribution of the intra-regional differences is the largest compared to the inter-regional differences, and the influence of the cross-over problem of the inter-regional samples is stronger. The overall decline in the overall Gini coefficient classified by K-means also supports that the regional differences in the income levels of Chinese residents are narrowing. The overall intra-regional differences show fluctuations while declining, indicating that the gap between the two categories of regions is decreasing and there is a trend of club convergence. The fluctuations in the differences between the two categories of the regions are decreasing, again indicating that the gap between the two categories is gradually narrowing. The inter-regional differences have the largest contribution; the intra-regional differences have a strong impact; and the impact of the cross-over problem is small.

Kernel density estimation: For the north–south classification, the height of the main peak position of the southern distribution curve decreases, whereas the width remains basically unchanged. The side peaks gradually approach the main peak. The right trailing tail always exists, whereas the extension gradually narrows, indicating that the unevenness of development within the south is narrowing. The height of the main peak position of the northern distribution curve fluctuates and decreases; the width first narrows and then widens; and the right trailing tail always exists, whereas the extension first widens and then narrows. The right tail is always present, and the extension is widened and then narrowed, indicating that the north is showing a convergence trend.

According to the classification by K-means, the height of the main peak of the first class distribution curve fluctuates down, while the width fluctuates narrower. The side peaks gradually disappear, and the whole presents a right trailing tail. The extension fluctuates narrower, indicating that the whole presents a convergence. The height of the main peak of the fourth class distribution curve decreases, while the width fluctuates narrower. More side peaks appear in the early stage but gradually decrease. The right trailing tail is always present, and the extension is gradually narrowed, which means that the overall trend is also convergent.

Markov chain: The elements on the main diagonal of both the north and south are larger than the non-diagonal elements, and the convergence phenomenon is more obvious for the low- and high-level clubs in the south and the high-level clubs in the north. The rank-shifts in both the south and north occur in adjacent types, and the probability of decline is smaller than the probability of upward shift, indicating that there is a small risk of decline. When classified by K-means, the elements on the main diagonal of both the classes are larger than those on the non-diagonal, indicating that there is club convergence. The convergence of the high level of both the classes and the low level of the first class is more obvious. The rank-shift of both classes occurs in both the adjacent types, and there is a "jump" shift, but the probability of decline is smaller than that of upward shift. The probability of downward shift is smaller than the probability of upward shift, indicating that the risk of downward shift is higher than the probability of downward shift in both categories.

(2) Different convergence method

In the convergence analysis, the method used is a combination of β-convergence and heat map. However, the conclusions drawn from a single convergence model cannot be ruled as robust. Therefore, we adopted the widely used α-convergence model and four divisions, namely overall national, north–south, the four major sectors, and K-means, to study the convergence of China's per capita income level in parallel. The conclusions

remain essentially the same (see Figure A.6 in the appendix).

After including the historical and forecast data in the same framework for the α convergence analysis, we found that the trends of the σ coefficient and coefficient of variation of the overall national income level in China are relatively similar, both for the historical interval from 1993 to 2020 and the observation period from 1993 to 2035 with the inclusion of the forecast data. There is a fluctuating downward trend, similar to the result of the β-convergence analysis, indicating that China's per capita income will take a converging trend toward 2035. In the historical interval, the σ coefficient and the coefficient of variation show a convergence trend for the residents' income from 1993 to 2020 as a whole; after adding the forecast data, the trends of the σ coefficient and the coefficient of variation are still relatively similar. The overall period from 1993 to 2035 shows a fluctuating convergence trend.

For the north–south classification, the overall α-convergence is similar in the two regions, but the fluctuation is greater in the south. In the historical interval, the south and north double coefficient trends are essentially the same, showing a convergence trend but being more obvious in the south. After adding the forecast data, the coefficient trends of the south and north double coefficients in the future are more different, and the overall data show a fluctuating convergence trend from 1993 to 2035, whereas the north is less volatile in comparison. For the four major sectors classification, the income levels of the residents in the four major sectors show different trends, among which the eastern and middle sectors show fluctuations and convergence regardless of the historical period or the inclusion of forecast data, whereas the northeastern and northwestern sectors show fluctuations and wandering trends. For the K-means classification, the first and fourth parts show fluctuating and diverging trends, among which the fourth part is more volatile. The two coefficients of the first part show a fluctuating rise in the historical period, but the final rise is small. There is a tendency of divergence but to a lesser extent, and the whole part shows fluctuating and diverging trends in the observation period. The fourth part shows a trend of divergence and then

convergence in the historical period, and the whole part shows fluctuating and converging trends.

(3) Different data span

In the above analysis, the historical data and future data were analyzed as a whole, but the LSTM network fully absorbed the information of the historical data, which does not exclude the possibility that the forecast data "reinforced" the characteristics and trends of the potential real data. To avoid the effects of such path dependence that leads to biased conclusions, we repeated the empirical analysis with pure historical data, and the historical findings of other research methods are analyzed at the corresponding place. The conclusions remain essentially unchanged (see Table A.4 in the appendix).

Taking the period from 1993 to 2020 as a whole, the income level of the residents in the whole country and each region has a steady state, and there is a club convergence phenomenon. There are generally adjacent types of transfers, and only a few cross-type transfers exist. However, in the 1993–2020 period, the level of residents' income shows a predominantly upward trend. The overall diagonal elements are always larger than the non-diagonal elements; the different levels of residents' income are more stable; and there is club convergence. The low- and high-level club convergence is more obvious; the level shifts all occur in adjacent types; the development of residents' income level is gradual; there is a risk of downward shift of residents' income level; and as the level of high-quality economic development decreases, the probability of downward shift increases accordingly.

For the north-south classification, there is a convergence of clubs, whereas the low-level and high-level clubs in the south are obvious. The convergence of the high-level clubs in the north is more obvious. The grade shift in both the south and north occurs in the adjacent types, and the probability of decline is smaller than the probability of upward shift. For the four major sectors classification, the club convergence exists as before, whereas the high-level clubs in the east, middle, and west

are more obvious. The low-level and high-level clubs in the northeast are more obvious. The four major sectors' rank-shifts all occur in adjacent types, and the probability of decline is smaller than the probability of upward shift. For the K-means classification, there is club convergence in both divisions, and the high-level clubs in both divisions are more obvious. The rank-shifts in both the divisions occur in adjacent types, and there are also "jump" shifts, but the probability of decline is smaller than that of upward shift.

V. Conclusions and Implications

Using the per capita GDP of Chinese provinces from 1993 to 2020, this paper analyzed the characteristics of China's historical and future economy-wide convergence and club convergence in an all-round and three-dimensional manner under the two major time divisions of history and the future. We adopted multiclassification perspectives of the whole country, north and south regions, the four major segments, and K-means and used multiple methods such as α-convergence, absolute β-convergence, heat maps, decomposition of the Dagum's Gini coefficient, estimation of kernel densities, and Markov chains to carry out a multi-dimensional exploration of the dynamics of distribution of the level of residents' income and of the regional disparities. Our comprehensive approach makes it likely that the results are robust and reliable.

The main conclusions of this paper are as follows. From the point of view of convergence, the country as a whole will move toward 2035 with an absolute convergence trend, and common wealth will be further realized. The north and south, the four major sectors, and the two categories of regions will continue to have the phenomenon of club convergence, and the intra-regional economic level will be further converged. From the perspective of regional differences, the overall Gini coefficient will show a decreasing trend, and the differences in the coming period will mainly come from the inter-regional differences. The intra-regional differences will show a decrease of different magnitudes, but some regions, especially the four major sectors, will

maintain a large proportion of intra-regional differences or hypervariable density contribution, and some regions will have an upward trend. From the perspective of the distribution dynamics, both the whole country and the regions under the three classifications will show a trend of "absolute difference narrowing," especially during the period from 2021 to 2035. The ups and downs will be more dramatic, indicating that China's residents' income level will advance toward modernization under the situation of both crisis and opportunity. Club convergence will continue to exist. Neighborhood transfers will continue to be common; cross-type transfers will continue to be a minority; there will be a "leapfrog" upward movement from the low to high levels; downward risks will continue to exist, but the probability of upward development is higher; and there is the possibility of leapfrog development.

Based on the above conclusions, this paper draws the following insights for decision-making and policy guidance. First, we should recognize the shortcomings presented in the process of historical residents' income level. Even if the earlier years are taken as the initial years, the national convergence trend is one of frequent fluctuations and changes. There is dispersion in a part of the study period, which reflects the fact that even if the national economic development is rising in the aggregate, the internal distribution is unbalanced, which hinders the common prosperity goal of development and even makes it retreat slightly in some years. While insisting on the development of the economy of the rich and advantageous regions, we should insist on the timely adoption of efficient and coordinated policies and other support measures to avoid polarization.

Second, we should pay attention to regional differences in the development of the population's income. Based on the three classifications, inter-regional disparities are the first problem to solve. Moreover, we should prevent the intra-regional disparities from rising suddenly. We should strengthen inter-regional exchanges and cooperation and rationalize the allocation of resources from the north and south and among the four major sectors. We should make full use of and take advantage of the spatial spillover

effect of the overall development and of club convergence, and we should make use of the radiation effects of the developed regions on the relatively backward regions to narrow the regional gaps and to prevent regional imbalances from further expanding.

Third, we should adopt locally adapted development strategies for different regions to drive the national and regional economies to a higher level of development. The transfer characteristics of the residents' incomes under a variety of division methods are dominated by neighboring types. Provinces, especially in the future, should focus on preventing and resolving the risks of downward transfers, such as the eastern part, which is at a higher economic level and is destined to need to undertake more cutting-edge technological pursuits and bear trial-and-error costs. We should mitigate against the risk of transferring from a high level to a medium-to-high level or even a "leaping" decline to a medium-low level. Some regions need to make efforts to realize an upward transfer or even an upward "leaping" rise. The overall relatively backward western provinces should learn from the successful development experiences and upgrade their economies and grasp the rare opportunities of the digital economy and industrial transfer era.

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