Academic Education Publishing House
Economic Society and Humanities Vol. 1 No. 9, 2024

Spatiotemporal Evolution of High-Quality Population Development in China under the New Development Paradigm

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Abstract: This paper develops an evaluation index system to assess high-quality population development in China. Employing the entropy weight method to calculate composite scores, we examine the temporal evolution of high-quality population development from 2010 to 2022. Kernel density analysis is applied to determine score distributions across the nation and various regions, while the spatial Markov regime-switching model is used to analyze spatial evolution trends. The results reveal that (1) China's high-quality population development score has shown a steady upward trend, mainly driven by increases in scores for population distribution and structure, while the score for population size has declined. There are also regional imbalances, with the eastern and central regions leading, and the western and northeastern regions lagging. (2) Kernel density analysis reveals an upward shift in scores nationally, with a higher density of high scores in the eastern and central regions, forming a secondary peak on the right side of the distribution. In the western region, there is also a rightward shift in the primary peak, with a thick left tail remaining. (3) Using the comprehensive scores, we apply a spatial Markov regime-switching model to analyze spatial evolution trends, showing a dominant "club convergence" effect nationwide. Low-level and high-level population regions remain relatively fixed in their categories, with low-level areas struggling to transition to higher levels through internal growth, while high-level areas have established a stable economic base that attracts skilled populations. This entrenched disparity may hinder high-quality population development at the national level.

Keywords: High-Quality Population Development; Entropy Weight Method; Kernel Density Estimation; Markov Regime-Switching Model; Spatial Markov Regime-Switching Model

1. Introduction

Chinese leadership first introduced the concept of a "new development pattern" from a strategic perspective in their work on Some Major Issues in China's Long-Term Economic and Social Development Strategy. This new development pattern refers to a model centered on a domestic economic cycle that is open to dual international and domestic cycles, rather than a closed single domestic cycle or a self-contained micro-cycle. Understanding this new development pattern involves three main aspects: first, optimizing the basic economic structure to identify the fundamental path of China's development; second, unblocking all stages of production, distribution, circulation, and consumption by addressing bottlenecks and connecting fragmented points; and third, expanding high-level openness to the outside world. The emphasis on the domestic cycle as the mainstay is intended to anchor production, distribution, circulation, and consumption more firmly in the domestic market. This is not only a proactive strategic adjustment to profound changes in the international economic environment but also a necessary requirement for China's economic development. However, a domestic cycle as the primary focus is by no means an attempt at isolationism or a closed-loop economy; rather, it underscores achieving economic circulation on a global scale. Structural reform is central to facilitating the domestic cycle, requiring synchronized demand- and supply-side structural reforms[1].

On May 5, 2023, Chinese leadership emphasized in a meeting the need to support modernization efforts through high-quality population development, providing an essential guideline for China's modernization process. Looking back, China's population policy has shifted from a focus on "strength in numbers" in the early

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years of the People's Republic of China, to a policy of family planning during the reform and opening-up period, and now to an emphasis on quality as the population dividend gradually diminishes. The meeting highlighted, "Currently, China's population development is characterized by trends of declining birth rates, an aging population, and regional population differentiation. We must comprehensively understand and correctly assess the new population development situation." This assertion reveals the complex circumstances surrounding China's population development today. Unlike in the past, the current stage requires a greater focus on optimizing population structure and improving quality, marking a shift in population policy from "quantity control" to "quality enhancement." Thus, promoting high-quality population development is not only a necessary measure to address issues like declining birth rates and an aging population but also a critical step in achieving modernization. Improving the quality of the population, optimizing its structure, and enhancing distribution will provide solid human resources for sustainable national development.

"Development" entails more than changes in quantity, scale, and form; it emphasizes the evolution of things from a lower to a higher level, from an old to a new quality through the dynamics of internal contradictions. Population development follows this principle, as it is a natural outcome of the advancement of productive forces and social production methods. This evolution is reflected in the population's scale, quality, structure, and distribution, aligning with socio-economic and ecological development, gradually advancing from lower to higher stages[2]. Population is the cornerstone of building a modernized and powerful nation and serves as a vital foundation for advancing China's modernization[3]. Research on population development indicators began at the end of the last century, mainly focusing on population modernization. Its primary framework includes population reproduction modernization, quality modernization, and structural modernization[4,5]. China's high-quality population development currently faces challenges such as declining birth rates, population aging, negative population growth, and regional population differentiation. With persistently low fertility rates, China's population has entered an era of negative growth, which will be difficult to reverse in the short term[6]. This trend is evident in China's population development trajectory, where, as of 2020, the total fertility rate of women of childbearing age was only 1.3, with a rapid decline in the number of women in this age group, delays in initial childbirth, and ultra-low fertility rates expected to persist[7]. Furthermore, population structure is changing, with a reduction in the working-age population, improvements in health levels and education, an intensifying aging population, and increased mobility. Thus, we must adopt a systemic perspective and developmental mindset to rationally, objectively, and scientifically assess the new features and trends in China's population development. Recognizing, adapting to, responding to, and guiding the new situation in population development requires a comprehensive, in-depth, and accurate understanding of high-quality population development. Uncovering advantages within the overarching trends of population development that facilitate high-quality population development is a significant task for scholars in this era of significant changes. Consequently, previous frameworks focused on population structure and reproduction are no longer sufficient for studying China's population within the new development pattern, nor can they measure high-quality population development in China. It is therefore necessary to explore a new indicator system to assess high-quality population development within the new development pattern.[8]

As shown in Figure 1, from the relationship between high-quality population development and the new development pattern, it is evident that whether it is a domestic cycle centered on production and consumption or a dual domestic-international cycle focused on imports and exports, population is essential. Production and exports require a working population to participate, while consumption and imports create demand. Therefore, promoting high-quality population development is a fundamental requirement in advancing modernization within the new development pattern. In the past, population research and evaluation frameworks often emphasized single indicators such as population size and growth rates, focusing on the "quantity advantage" of the demographic dividend. This approach has overlooked the profound impact of population quality, structure, and spatial distribution on economic and social development.[9] Especially amid rapid industrialization and urbanization, overemphasis on population quantity has led to issues like resource pressure, environmental degradation, and urban challenges. As trends of slower population growth, aging, and declining birth rates become increasingly prominent, single-dimensional evaluations can no longer meet the demands of population development in the new era[10].

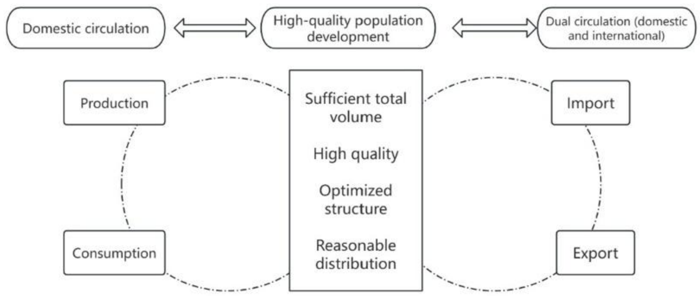


Figure 1: The Relationship between the New Development Pattern and High-Quality Population Development

Therefore, high-quality population development within the new development pattern requires a more comprehensive and in-depth evaluation system. Given the limitations of past research, future evaluations of population development should establish a multi-dimensional framework centered on " High Quality, Adequate Quantity, Structural Optimization, and Rational Distribution."[11]

High Quality: Improving educational attainment, health levels, and labor skills. A high-quality population is essential for technological innovation, industrial upgrading, and social progress. Therefore, raising population quality should be a critical indicator of high-quality development.

Adequate Quantity: Ensuring a reasonable labor force size amid slowing population growth to support economic growth and social stability. The past focus on sheer population scale can no longer meet the needs of modern economic development; future emphasis should balance population size with social demand.

Structural Optimization: Achieving balanced gender and age structures to address issues of aging and labor shortages. Optimizing population structure not only helps alleviate social security pressures but also provides sustainable momentum for economic growth.

Rational Distribution: Aligning population spatial distribution with economic and social development. A rational population distribution promotes efficient resource utilization, fosters regional balanced development, and prevents issues of excessive concentration or imbalance that lead to resource waste and social challenges. By systematically evaluating these four dimensions—quality, adequacy, structural optimization, and rational distribution—population research within the new development pattern will become more targeted and scientific, providing a stronger population base for China’s modernization efforts. This evaluation framework not only corrects the previous single-dimensional research bias but also offers comprehensive solutions to the complex population development issues in the context of the new development pattern.

2. Construction of the Indicator System and Data Sources

2.1 Construction of the Indicator System and Data Sources

Based on the concept of high-quality population development, the primary indicators are structured around four dimensions: sufficient total volume, high quality, optimized structure, and reasonable distribution. "Sufficient total volume" is characterized by two aspects: resident population size as a proxy for total population and both natural growth and birth rates as proxies for population growth. "High quality" is represented through three components—physical, educational, and moral qualities—corresponding to the tertiary indicators of per capita life expectancy, average years of education, and the number of traffic accidents. "Optimized structure" is reflected in age and labor structures, measured by the dependency ratios for children (ages 0–14) and the elderly (65+), as well as labor participation and productivity. Finally, "reasonable distribution" encompasses both urban-rural and spatial distribution, with tertiary indicators including the urbanization rate and the proportion of the floating population. This approach results in four primary indicators, eleven secondary indicators, and twenty-one tertiary indicators.

The data used in this study derive from the annual records for China's 31 provinces between 2010 and 2022, sourced from publications such as the China Statistical Yearbook, China Health Statistics Yearbook, China Population and Employment Statistical Yearbook, China Population Census Yearbook, China Labor Statistical Yearbook, China Environmental Statistical Yearbook, provincial statistical yearbooks, and datasets published on the National Bureau of Statistics website. Missing values were filled using linear interpolation.

2.2 Research Methods

2.2.1 Entropy Weight Method

The entropy weight method is applied to calculate the weight of each indicator and to obtain the composite high-quality population development index as well as the sub-indices for each of the four dimensions. This method effectively considers the distribution of subsamples and addresses overlapping differences within the data, allowing for a more refined understanding of regional disparities. The calculation steps are as follows:

Data Standardization Different types of indicators require specific standardization approaches:

1. Positive indicators:

$$z_{ij} = \frac{x_i - \max(x_i)}{max - min} \#(1)$$

Negative indicators:

$$z_{ij} = \frac{\min(x_i) - x_i}{max - min} \#(2)$$

where z_{ij} is the standardized value of the j-th indicator for the i-th sample.

2. Calculating Indicator Proportions

$$p_{ij} = \frac{z_{ij}}{\sum z_{ij}} \#(3)$$

3. Entropy Calculation

$$e_j = - k \sum_{i=1}^{m} p_{ij} \ln(p_{ij}) \#(4)$$

Where k=1/ln(m),(based on the sample size), so $0 \leq e_j \leq 1$

4. Information Utility Value Calculation

$$d_j = 1 - e_j \#(5)$$

5. Weight Calculation

$$w_j = \frac{d_j}{\sum d_j} \#(6)$$

6. Comprehensive Score Calculation

$$s_i = \sum_{i=1}^{n} w_j z_{ij} \#(7)$$

2.2.2 Kernel Density Estimation

Kernel density estimation is a nonparametric approach used to depict the distribution of a random variable through a continuous density curve, with significant applications in analyzing spatial distribution imbalances. Assuming that random variable XXX has a density function, it is represented as:

$$f(x) = \frac{1}{Nh} \sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right) \#(8)$$

where N is the sample size, h the bandwidth, K the kernel function, X_i independent observations, and x the mean. The kernel function serves as a weighting or smoothing function and must satisfy the following conditions:

$$\begin{cases} \lim_{x\to\infty} K(x) = 0 \# \\ K(x) \geq 0 \quad \int_{-\infty}^{+\infty} K(x)\, dx = 1 \# \\ \sup K(x) < +\infty \quad \int_{-\infty}^{+\infty} K^2(x)\, dx < +\infty \#\#\# \end{cases} \#(9)$$

This study utilizes a Gaussian kernel function to estimate the distribution and evolution trends of the high-quality population development index across China's three major regions. Kernel density estimation is sensitive to bandwidth hhh, where larger hhh values yield smoother curves but lower accuracy, while smaller hhh values offer higher accuracy with more jagged curves. In practice, smaller hhh values are chosen to ensure smooth curves. This method reveals the distribution characteristics of China's high-quality population development index across regions, including location, distribution shape, peak count, and distribution range, thereby illustrating its dynamic evolution.

2.2.3 Markov Regime-Switching Model

The traditional Markov regime-switching model classifies continuous data into K types and computes the probability distribution and transition trends for each type under discrete conditions of time and state, thereby elucidating regional characteristics in high-quality population development. A Markov chain is a stochastic process $\{X(t), t \in T\}$, where the index set T corresponds to each period, and finite states correspond to the state number of the random variable. For any period t and states j,i, a first-order Markov chain property is expressed as follows:

$$\begin{aligned} P\{X(t) = j \mid X(t-1) = i, X(t-2) \\ = i_{t-2}, \dots, X(0) = i_0\} \\ = P\{X(t) = j \mid X(t-1) = i\} \end{aligned}$$

Assume that the state space of the Markov process $\{X(t), t \in T\}$ is I.

$$p_{ij} = p\{X(t+1) = j \mid X(t) = i, i, j \in I\}$$

The probability matrix of state transition, denoted as p_{ij}, is calculated as:

$$p_{ij} = \frac{n_{ij}}{n_j} \#(10)$$

where n_{ij} is the number of transitions from state i to state j within the observation period, and n_{ij} is the frequency of state j in the initial period.

The spatial Markov chain model incorporates "spatial lag," assessing the impact of neighboring cities on the transition probability of a given area. This requires the use of a spatial weight matrix (W), defined as $\sum_j w_{ij} y_j$, where w_{ij} is an element of W, i = j = 1…n, and y_j is the level in region j.[12]

Kernel density estimation, the traditional Markov regime-switching model, and the spatial Markov model are all nonparametric methods. Unlike parametric methods, these do not assume a specific distribution form, allowing for an evaluation based on information from random sampling alone, thereby achieving higher fitting accuracy and robustness. Each method has distinct focuses: kernel density estimation provides an overall view of regional distribution shapes; the Markov model analyzes changes in relative positions among provinces, addressing limitations of kernel density estimation in depicting intra-regional dynamics; and the spatial Markov model reveals the influence of spatial factors on development levels, compensating for the traditional Markov model's inability to capture spatial spillover effects.

3. Measurement and Analysis of the High-Quality Population Development Index

This study applies the entropy weight method to calculate the weights of each indicator, as shown in Table 1:

Based on socioeconomic development and geographic factors, this study divides China's 31 provincial-level regions into four categories: Eastern, Central, Western, and Northeastern regions.

The Eastern region includes ten provincial-level areas such as Beijing, Tianjin, and Shanghai.

The Central region includes six provincial-level areas such as Shanxi, Anhui, and Jiangxi.

The Western region includes twelve provincial-level areas such as Inner Mongolia, Guangxi, and Sichuan.

The Northeastern region includes three provincial-level areas: Liaoning, Jilin, and Heilongjiang.

Table 1. Indicator System and Weights

	Primary Indicator	Secondary Indicator	Tertiary Indicator & Nature	Weight
High-Quality Population Development Indicators	Sufficient Total Volume	Population Size	Resident Population (+)	0.1126
		Growth Rate	Natural Growth Rate (+)	0.0284
			Birth Rate (+)	0.0432
	High Quality	Physical Quality	Per Capita Life Expectancy (+)	0.0241
			Perinatal Mortality Rate (-)	0.0084
		Educational Quality	Average Years of Education (+)	0.0134
			Illiteracy Rate (-)	0.0098
			Average Number of Higher Education Students per 100,000 People (+)	0.0642
		Moral Quality	Number of Traffic Accidents (-)	0.0168
	Optimized Structure	Age Structure	Child Dependency Ratio (+)	0.057
			Elderly Dependency Ratio (-)	0.0279
		Socioeconomic Structure	Labor Participation Rate (+)	0.0326
			Proportion of Employment in Scientific and Technical Fields (+)	0.1152

			Labor Productivity (+)	0.104
	Reasonable Distribution	Urban-Rural Distribution	Urbanization Rate (+)	0.0326
			Population Migration Rate (+)	0.0071
			Proportion of Floating Population (+)	0.1517
		Spatial Distribution	Urban Water Supply Coverage Rate (+)	0.0033
		Ecological Harmony	Forest Coverage Rate (+)	0.0961
			Per Capita Green Space in Parks (+)	0.0374
			Per Capita Sulfur Dioxide Emissions (-)	0.0141

3.1 Evolutionary Trends in High-Quality Population Development at the National Level

Figure 2 illustrates the overall trend in China's high-quality population development composite index from 2010 to 2022. The bar chart shows a consistent upward trend, suggesting that China's population development has been advancing steadily toward the objectives of high quality, sufficient scale, optimized structure, and balanced distribution. Analysis of primary indicator scores reveals that population structure consistently ranks highest, followed by population distribution. However, since 2018, the growth rate for population distribution has slowed, widening the gap between it and population structure. Population scale ranked third until 2019 but was subsequently overtaken by population quality due to a decline in the scale score. Although population quality initially had the lowest score, it has shown rapid growth since 2018, highlighting notable improvements in educational equity and public healthcare, which have effectively raised the population's education levels and health standards.

The improvement in population structure indicates significant progress in labor force quality as China transitions from low-end, labor-intensive industries toward emerging sectors with higher added value. In contrast, the relatively steady growth in population distribution suggests that China's urbanization process may be reaching its peak. Moving forward, urban-rural development should focus less on expanding cities and more on fostering collaborative and mutually beneficial relationships between urban and rural areas in alignment with the new development paradigm.

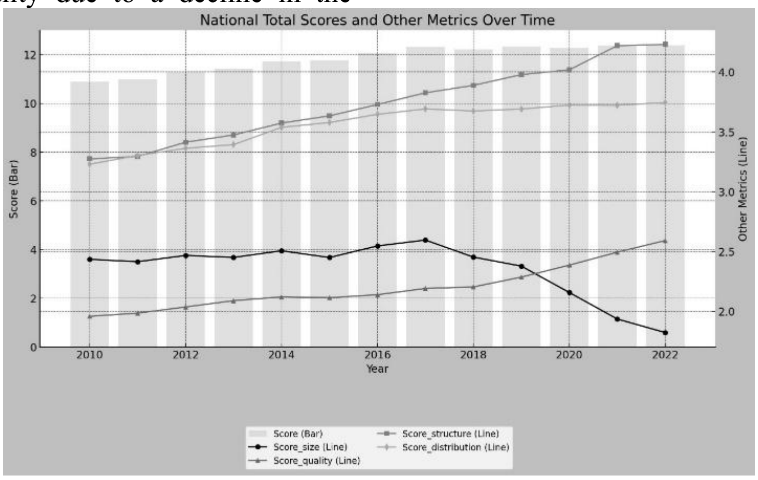


Figure 2. Trends in the Composite Index of High-Quality Population Development in China

Table 2. Decomposition of Differences in High-Quality Population Development Nationwide

Year	Total Score	Size		Quality		Structure		Distribution	
		Score	Contribution	Score	Contribution	Score	Contribution	Score	Contribution
2010	10.8952	2.4343	22.34%	1.9584	17.98%	3.2733	30.04%	3.2291	29.64%
2011	10.9958	2.4145	21.96%	1.9848	18.05%	3.2942	29.96%	3.3022	30.03%
2012	11.2780	2.4669	21.87%	2.0363	18.06%	3.4127	30.26%	3.3621	29.81%
2013	11.4058	2.4503	21.48%	2.0891	18.32%	3.4736	30.45%	3.3928	29.75%
2014	11.7366	2.5056	21.35%	2.1207	18.07%	3.5730	30.44%	3.5373	30.14%
2015	11.7740	2.4495	20.80%	2.1137	17.95%	3.6331	30.86%	3.5777	30.39%
2016	12.0589	2.5463	21.12%	2.1386	17.73%	3.7279	30.91%	3.6461	30.24%

2017	12.3035	2.5953	21.09%	2.1913	17.81%	3.8257	31.09%	3.6911	30.00%
2018	12.2191	2.4531	20.08%	2.2039	18.04%	3.8881	31.82%	3.6740	30.07%
2019	12.3318	2.3777	19.28%	2.2858	18.54%	3.9778	32.26%	3.6905	29.93%
2020	12.2842	2.1573	17.56%	2.3859	19.42%	4.0178	32.71%	3.7231	30.31%
2021	12.3706	1.9357	15.65%	2.4938	20.16%	4.2193	34.11%	3.7218	30.09%
2022	12.3882	1.8226	14.71%	2.5914	20.92%	4.2300	34.15%	3.7443	30.22%

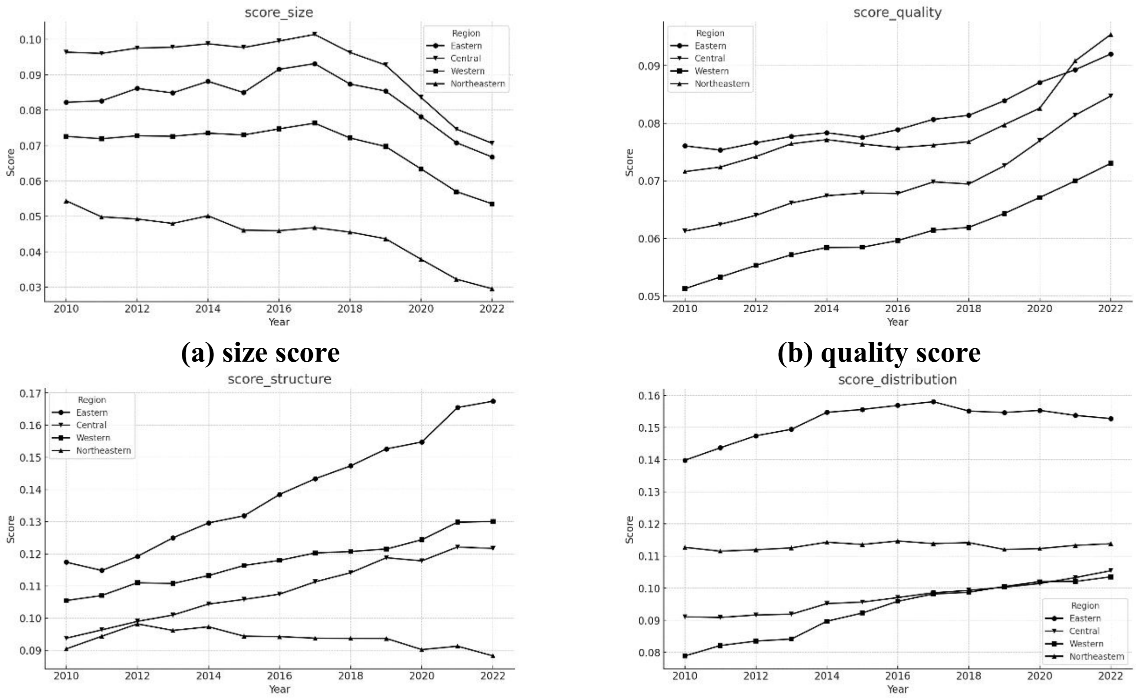
By calculating the contribution rate of each primary indicator score (i.e., the proportion of each primary indicator score relative to the total score), this analysis identifies the key variables influencing high-quality population development. As shown in Table 2, population structure and distribution scores are relatively high, together accounting for over 60% of the total contribution. In contrast, the score for population scale has shown a consistent decline, closely linked to trends of low birth rates, population aging, and negative growth in China

In contrast, population quality and structure scores have continued to rise, reflecting an increasing policy and social emphasis on improving population quality and optimizing population structure. Population structure and distribution contribute the most to high-quality population development scores, each maintaining a contribution rate around 30%. This suggests that the essence of high-quality population development is not in simple expansion of scale but rather in structural optimization and balanced distribution. Accordingly, greater attention should be directed towards adapting the existing labor force to the demands of dual circulation, developing a new, high-quality productivity supply within the new development paradigm, and promoting sufficient employment opportunities for highly educated talent to enhance labor productivity.

Furthermore, achieving harmony between people and society, as well as between society and the environment, is essential. The new development paradigm is not merely about expanding GDP but rather about achieving prosperity, democracy, civility, harmony, and ecological well-being. It is imperative to embrace the principle that “lucid waters and lush mountains are invaluable assets” to continually meet people’s demand for a sustainable environment, fostering a population development model that harmonizes human and natural systems.

From the perspective of scale scores, the Eastern region has consistently held the highest position, closely linked to its advanced economic development and strong population attraction. With its economic prosperity and concentration of resources, the Eastern region has long drawn a substantial population. Recently, however, high housing prices, high living costs, and declining fertility rates have slowed population growth. The Central region, while scoring below the East, has remained relatively stable. Serving as the "hinterland" of the Eastern region, the Central region has absorbed significant industrial and population transfers from the East. This has slowed its population decline, reflecting the success of policies focused on industrial relocation and population inflow. In contrast, the Western region shows a lower and slower growth in population scale, indicating limited attractiveness to talent. Meanwhile, the Northeast exhibits the most concerning trend, with a persistent decline. Therefore, enhancing population scale in the Northeast remains a critical factor in advancing high-quality population development nationwide.

In terms of population quality, the Eastern and Central regions, with their rich educational and healthcare resources, maintain high concentrations of skilled labor, providing vital support for high-quality economic growth. Conversely, the Western region reflects lower population quality, indicating a shortfall in resource accessibility and development. Interestingly, the Northeast has maintained relatively high levels of population quality, even surpassing the Eastern region in recent years. Around 2020, the COVID-19 pandemic likely impacted health metrics in densely populated Eastern regions, resulting in slight declines in indicators such as life expectancy. In contrast, the Northeast’s lower population density and cooler climate, which inhibit virus spread, helped sustain its health levels. Additionally, as an early industrial center in modern China, the Northeast has retained a substantial base of healthcare and educational resources, keeping its population quality among the nation’s highest—a model worth studying for other regions.



(a) size score **(b) quality score**

(c) structure score **(d) distribution score**

Figure 3. Line Chart of Primary Indicator Scores across Different Regions

For population structure, scores in the Eastern region have steadily increased, with notable acceleration after 2016. This growth can be attributed to economic advantages, ample job opportunities, and talent recruitment policies that boost indicators like labor participation rates. The Central region has also shown a gradual yet stable upward trend, with scores rising from 0.093 in 2010 to 0.121 in 2022. This trend reflects government support for the “Rise of Central China” strategy and infrastructure development, encouraging population settlement in the region. The Western region exhibits similar patterns to the Central region, with even more robust growth in recent years. However, the Northeast has experienced a sustained decline, indicating that the outflow of young labor has significantly impacted its population structure.

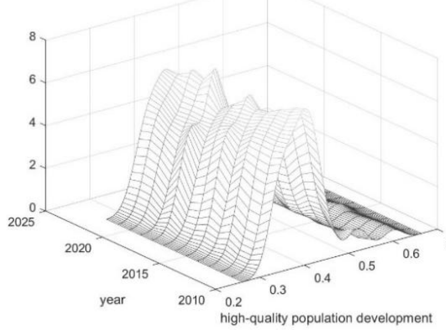
Population distribution data show an upward trend in the Eastern region, though slight declines and fluctuations have occurred since 2017. Despite this, the Eastern region still far surpasses other areas, reflecting its strong population pull, though this attraction may now be gradually diffusing to other economic clusters. The Central region’s score has steadily increased from 2010 to 2022, showing stable growth. This trend is attributable to the “Rise of Central China” strategy, which improved Central urban clusters through economic development and infrastructure backed by spillover effects from Eastern cities. Consequently, some labor that had previously migrated to the East has since returned to the Central region for employment and lifestyle opportunities. The Western region’s score has also risen, particularly following the advancement of the "Western Development" policy, which enhanced infrastructure and economic conditions, accelerating population inflows post-2015. In contrast, the Northeast shows relatively stable scores from 2010 to 2022 with minor fluctuations but lacks significant growth and may even be surpassed by the Western region. Although stability in population development can be beneficial, the Northeast still faces substantial challenges with population outflow and economic constraints, underscoring the severity of its demographic issues.

4. Dynamic Evolution of High-Quality Population Development in China

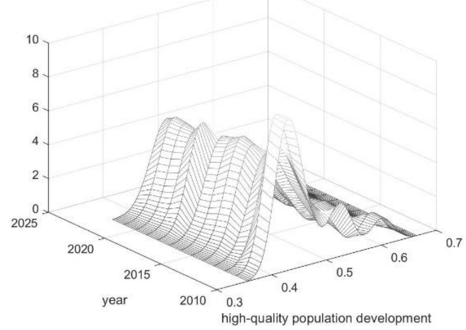
This study applies the kernel density estimation method to further examine the dynamic evolution of population development in China, revealing the distribution, shape, peak counts, and spread of high-quality population development at the national level, as well as within the Eastern, Central, and Western regions. This analysis provides insights into the spatiotemporal evolution of population scale, quality, structure, and distribution. Due to the limited sample size in the Northeast, a separate analysis of this region's distribution is not considered meaningful and is therefore excluded. Details are provided in Figure 4 and Table 3.

Table 3. Dynamic Evolution Characteristics of Population Quality Development Nationwide and in the Eastern, Central, and Western Regions

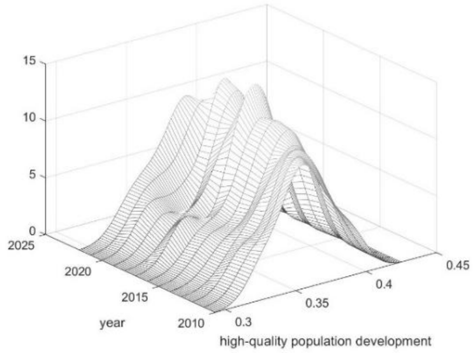
Region	**Position**	Shape	Spread	Polarization Trend
Nationwide	Shifts to the right	main peak becomes higher	Right-Tailed	Multi-Polarization
Eastern	Shifts to the right	main peak becomes shorter, and the width expands	Right-Tailed	Multi-Polarization
Central	Shifts to the right	main peak becomes higher	No Tail	Uni-Polarization
Western	Shifts to the right	main peak decreases first and then increases	Right-Tailed	Multi-Polarization



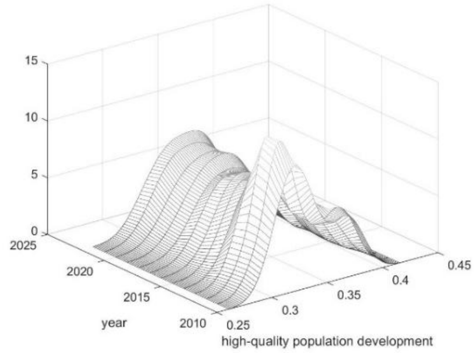
(a) Kernel Density Curve of High-Quality Population Development Nationwide



(b) Kernel Density Curve of High-Quality Population Development in the Eastern Region



(c) Kernel Density Curve of High-Quality Population Development in the Central Region



(d) Kernel Density Curve of High-Quality Population Development in the Western Region

Figure 4. Kernel Density Curves

National-level kernel density analysis reveals a decline in distribution kurtosis over time, indicating a reduction in clustering and an increase in interprovincial variance. A rightward skew and even secondary peaks on the right suggest clustering among distinct urban regions, with increased density at higher scores reflecting significant improvements in population development levels across certain areas. In specific years, density concentrations and sparse areas emerge, likely reflecting breakthroughs in development in some regions, while others exhibit more stagnant growth.

In the Eastern region, scores display multiple peaks across different years, indicating significant temporal fluctuations in population development quality. Over time, the peak of the density curve shifts rightward, signaling a steady improvement in population quality in the East. The multi-peak phenomenon implies rapid advancements in population quality within certain cities, potentially driven by policy incentives or economic growth.

The Central region follows a similar trajectory to the national trend, with a rightward tail indicating gradual improvements in population quality. Particularly after 2015, the score distribution shifts towards higher levels, reflecting ongoing progress. Multi-peak distributions in various years indicate considerable internal variation within the region, where some cities have advanced rapidly, while others lag behind. This variation is evident in the significant intervals between primary and secondary peaks in certain years, suggesting that while some cities have achieved substantial progress in high-quality population development, others remain in earlier stages. Despite these regional disparities, density distributions between 2015 and 2022 show a gradual smoothing, indicating a convergence in development rates across cities.

In the Western region, high-quality population development has been comparatively slower, though the main peak also shifts rightward, suggesting an overall positive trend. Between 2010 and 2015, multiple peaks reflect a wide range of development levels across cities, suggesting that certain cities progressed rapidly due to policy or industrial stimuli, while others lagged. Post-2015, peak concentration around 0.3 suggests a reduction in disparities among cities within the Western region and an emerging trend toward regional equilibrium.

5. Forecasting the Trends in High-Quality Population Development

To forecast the trends in high-quality population development at the national level, this study applies the Markov regime-switching model to analyze the transition probabilities across different levels of population development. All provinces are categorized by population development level into four groups based on quartiles: low (L), medium-low (ML), medium-high (MH), and high (H). The three-year lagged transition probability matrix is then calculated (NaN indicates no sample data).

As shown in Table 4, for the national region, 72.94% of low-level areas remain at a low level, while 27.06% transition to medium-low, with no areas moving directly from low to higher levels. Among medium-low areas, 6.17% regress to low, 55.56% remain at medium-low, and 38.27% progress to medium-high. For medium-high areas, 69.33% stay at this level, while 30.67% advance to high. High-level areas exhibit the most stability, with 94.2% maintaining their status and only 5.8% reverting to medium-high.

In the Eastern region, where high-quality population development leads nationally, no low-level areas are observed. For medium-low areas, 16.67% remain at this level, while 83.33% advance to medium-high. Among medium-high areas, 46.15% stay at their level, while 53.85% progress to high. High-level areas are entirely stable, with 100% retention. Overall, the Eastern region demonstrates a pronounced upward trend, particularly with rapid transitions from medium-low to high levels.

Table 4. Three-Year Lagged Markov Transition Probability Matrix

t/(t+3)	Type	L	ML	MH	H
National	L	0.7294	0.2706	0.0000	0.0000
	ML	0.0617	0.5556	0.3827	0.0000
	MH	0.0000	0.0000	0.6933	0.3067
	H	0.0000	0.0000	0.0580	0.9420
Eastern	L	NaN	NaN	NaN	NaN
	ML	0.0000	0.1667	0.8333	0.0000
	MH	0.0000	0.0000	0.4615	0.5385
	H	0.0000	0.0000	0.0000	1.0000
Central	L	0.8333	0.1667	0.0000	0.0000
	ML	0.0000	0.6190	0.3810	0.0000
	MH	0.0000	0.0000	0.7727	0.2273
	H	0.0000	0.0000	0.4000	0.6000
Western	L	0.7167	0.2833	0.0000	0.0000
	ML	0.0323	0.5484	0.4194	0.0000
	MH	0.0000	0.0000	0.8519	0.1481
	H	0.0000	0.0000	1.0000	0.0000
Northeastern	L	0.6923	0.3077	0.0000	0.0000
	ML	0.2353	0.7647	0.0000	0.0000
	MH	NaN	NaN	NaN	NaN
	H	NaN	NaN	NaN	NaN

In the Central region, 83.33% of low-level areas remain unchanged, while 16.67% shift to medium-low. Among medium-low areas, 61.9% remain at this level, while 38.1% move up to medium-high. For medium-high areas, 77.27% remain stable, with 22.73% advancing to high. However, 40% of high-level areas regress to medium-high, with only 60% maintaining their high level.

In the Western region, 71.67% of low-level areas remain stable, while 28.33% advance to medium-low. Among medium-low areas, 54.84% stay at this level, while 41.94% transition to medium-high. For medium-high areas, 85.19% remain stable, with only 14.81% progressing to high. Notably, high-level areas in the West revert to medium-high 100% of the time within three years, indicating a lack of sustainability at high levels in this region. This trend is often accompanied by an outflow of skilled labor and an aging population, although notable mobility persists within the medium-low range.

In the Northeast, 69.23% of low-level areas remain at a low level, while 30.77% transition to medium-low. Among medium-low areas, 76.47% remain at this level, while 23.53% fall to low. The Northeast lacks regions with nationally high development levels, underscoring a critical need to address high-quality population development in this area.

Analysis of the transition matrix reveals several key insights: at the national level, the club convergence effect is predominant, with significant entrenchment at both low- and high-level areas (72.94% and 94.20%, respectively). This reflects limited upward mobility in low-level areas, while high-level areas retain their advantage through concentrated resources. The strong stability of high-level areas (94.2% retention) aligns with factors like population density, robust infrastructure, and high labor quality in major cities or economically advanced regions such as Beijing, Shanghai, and Guangdong. These areas attract substantial skilled labor and sustain innovation-driven economic growth. Low-level areas, by contrast, exhibit strong path dependency (72.94% retention), often characterized by population outflows, labor market imbalances, and a lack of innovative industry support. Economic challenges in remote, sparsely populated areas hinder upward transitions. Notably, there is significant mobility between medium-low and medium-high levels, with 38.27% of medium-low areas advancing, suggesting these regions may be locations of population influx (e.g., second-tier cities) that gradually enhance their economic position. Additionally, 30.67% of medium-high areas advance to high levels, indicating successful economic transformation in some regions that capitalize on population influx and the labor dividend.

Based on this analysis, priority should be placed on fostering rational population mobility, promoting labor market innovation, and supporting equitable quality of life across regions.

6. The Impact of Spatial Factors on High-Quality Population Development

The traditional Markov chain approach treats each region as an independent entity when examining the temporal evolution of high-quality population development across regions. However, as development levels improve across regions, the development level of one region can influence high-quality population development in neighboring regions. This section further analyzes these interactions using the spatial Markov chain method, based on an economic spatial weight matrix. The four regions selected for analysis—the Eastern, Central, Western, and Northeastern regions—allow for a detailed examination of how spatial proximity impacts transitions in high-quality population development. The analysis considers both a national perspective and individual regional clusters, calculating the transition probability matrix with a three-year lag.

Table 5. Spatial Markov Chain Transition Probability Matrix Nationwide

Type of Spatial Adjacency	t/(t+3)	L	ML	MH	H
National	L	0.7294	0.2706	0.0000	0.0000
	ML	0.0617	0.5556	0.3827	0.0000
	MH	0.0000	0.0000	0.6933	0.3067
	H	0.0000	0.0000	0.0580	0.9420
L	L	0.7872	0.2128	0.0000	0.0000
	ML	0.1429	0.6190	0.2381	0.0000
	MH	0.0000	0.0000	1.0000	0.0000
	H	0.0000	0.0000	0.0000	0.0000
ML	L	0.6286	0.3714	0.0000	0.0000
	ML	0.0571	0.4857	0.4571	0.0000
	MH	0.0000	0.0000	0.7500	0.2500
	H	0.0000	0.0000	0.3333	0.6667
MH	L	1.0000	0.0000	0.0000	0.0000
	ML	0.0000	0.5789	0.4211	0.0000
	MH	0.0000	0.0000	0.9167	0.0833
	H	0.0000	0.0000	0.0000	1.0000
H	L	0.0000	0.0000	0.0000	0.0000
	ML	0.0000	0.6667	0.3333	0.0000
	MH	0.0000	0.0000	0.4667	0.5333
	H	0.0000	0.0000	0.0714	0.9286

As shown in Table 5, in regions adjacent to low-level areas, 78.72% of low-level areas remain at the same level, highlighting significant path dependency. A modest 21.28% of these areas advance to medium-low, but none progress to higher levels. Among medium-low areas, 14.29% revert to low, suggesting some instability, while the majority (61.9%) maintain their status. Meanwhile, 23.81% transition to medium-high. All medium-high areas adjacent to low-level regions remain stable, with no movement to either higher or lower levels, reflecting high stability.

For regions adjacent to medium-low areas, 62.86% of low-level areas remain unchanged, showing path dependency similar to those adjacent to low-level regions, but to a lesser extent. Notably, 37.14% of low-level areas transition to medium-low, indicating that adjacency to medium-low regions offers some boost for upward movement. Among medium-low areas, 5.71% revert to low, potentially due to factors like the outflow of young labor. In contrast, 45.71% advance to medium-high, a rate significantly higher than the national average of 38.27%, suggesting that medium-low neighboring regions provide a favorable context for upward movement. Among medium-high areas, 75% maintain their current level, while 25% successfully move to high; however, this rate is lower than the national average, suggesting that proximity to medium-low regions may restrict upward mobility in some higher-level areas.

In areas adjacent to medium-high regions, 100% of low-level areas remain unchanged, indicating that support from medium-high regions alone is insufficient to improve low-level regions, possibly due to a siphoning effect that concentrates resources in higher-level areas, keeping lower-level areas stagnant. Meanwhile, 42.11% of medium-low areas move to medium-high, above the national average of 38.27%, indicating a positive impact of adjacency to medium-high regions on high-quality population development. Additionally, 8.33% of medium-high areas successfully transition to high, underscoring the stability of human resources and economic development in these areas, though additional support is needed for some regions.

When adjacent to high-level regions, 33.33% of medium-low areas move up to medium-high, illustrating a clear spillover effect of talent and resources from high-level areas that aids in improving high-quality population development. Additionally, 53.33% of medium-high areas transition to high, significantly above the national average of 30.67%, indicating a strong uplift effect from high-level regions on adjacent areas. Among high-level areas, 92.86% remain stable, highlighting their resilience and appeal, allowing them to continuously attract high-quality populations and maintain high-level development.

Summary of Analysis: Low-level regions exhibit substantial path dependency, with very low probabilities of upward movement even when adjacent to medium-high or high-level regions. In fact, 100% of low-level areas adjacent to medium-high regions remain unchanged, suggesting that high-level regions may exert a siphoning effect, drawing human capital and resources into more developed areas and compounding the challenges faced by less-developed regions. These areas typically encounter longstanding issues such as population outflow, aging, and weak economic foundations, making it difficult to escape low-level development traps. Medium-low regions display a mix of vulnerability and upward potential; although they exhibit some upward mobility when adjacent to medium-high or high-level areas (with transition probabilities of 42.11% and 33.33%, respectively), they also face risks of regression. Certain medium-low areas may revert to low, reflecting underdeveloped economic structures and immature labor markets. Such regions rely heavily on external policy support and economic stability, leaving them vulnerable to job market contractions and population outflows. Conversely, high-level areas demonstrate remarkable self-sufficiency (92.86% remain high) and contribute to the advancement of neighboring medium-high areas through spillover effects. This indicates that China's high-level areas have built strong economic foundations and a robust capacity to attract skilled talent. However, this concentration of resources can lead to regional imbalances, intensifying the development pressures on low- and medium-low regions, thereby posing challenges to balanced high-quality population development at the national level.

7. Conclusions and Recommendations

Overall, China has made initial progress in advancing high-quality population development, as indicated by a steadily rising population quality development index. Specifically:(1) Analysis of primary indicators reveals that the ongoing decline in population size poses a major challenge for high-quality development. However, improvements in population quality have partly offset this limitation. Meanwhile, stable, high levels of population structure and distribution continue to be key drivers of high-quality development. (2) The eastern and central regions maintain strong performance across metrics due to economic growth and supportive policies. In the west, factors other than population size are improving rapidly, though the region still needs to boost its overall attractiveness. In contrast, the northeast faces more significant challenges in both population structure and size. (3) Nationally, the concentration of high-quality population clusters has weakened, with an increase in inter-provincial variance and the emergence of a right skew or secondary peak, suggesting the formation of population clusters in certain provinces. Regional differences and temporal changes are evident in population development: the east shows continuous improvement in population quality, the central region exhibits considerable internal diversity but an overall trend toward convergence, and the west, though slower in progress, is generally advancing with decreasing urban disparities. (4) Examining population transition matrices, the eastern region demonstrates a strong shift towards higher levels, while the central region faces challenges in maintaining its high level. The west shows significant gaps in sustaining high-quality population development, and the northeast requires intensified efforts to elevate population quality. (5) Results from the spatial Markov model reveal a marked path dependency in low-level regions, which struggle to escape low-quality development even when adjacent to higher-level areas. This reflects the siphoning effect, where resources become more concentrated in high-level regions. While medium- to low-level areas show some upward potential, they also exhibit instability, with certain areas prone to falling back to lower levels, heavily dependent on external policy support. Medium- to high-level regions have stronger upward mobility, particularly when adjacent to high-level regions, which exert a pulling effect. High-level areas, on the other hand, show exceptional stability and the capacity to attract skilled populations, driving growth in nearby medium-high areas through spillover effects. However, this high concentration may exacerbate regional imbalances, placing development pressures on low and medium-low regions.

Based on these conclusions, the study offers the following recommendations:

1. To address the decline in population size scores, reforms in fertility policy should be prioritized to encourage childbearing. This involves enhancing support systems for post-childbirth care, alleviating families' concerns about education, healthcare, and child-rearing costs. Additionally, policies should focus on adapting the existing workforce to the needs of the dual-circulation strategy by fostering high-quality productivity suited to the new development paradigm and promoting full employment for highly educated individuals to improve labor productivity. A harmonious relationship between people, society, and the environment must be cultivated. The new development framework emphasizes not only GDP growth but also prosperity, democracy, civilization, harmony, and beauty. Adopting a "green is gold" approach is crucial to meeting the public's demand for environmental sustainability and building a population development model where people and nature coexist harmoniously.

2. To address regional imbalances, it is essential to intensify the Western Development Strategy and Northeast Revitalization Strategy. In the western region, infrastructure and transportation networks should be developed to improve connectivity and attract talent. Leveraging the "Western Development" strategy, green industries like renewable energy and advanced materials, as well as the digital economy and e-commerce, should be promoted to drive innovation and employment. The northeast should focus on upgrading traditional industries, revitalizing old industrial bases, and attracting skilled talent. Its agricultural strengths can be harnessed by advancing smart agriculture and the food processing industry, attracting modern agricultural talent. Both regions require targeted talent attraction policies, such as housing subsidies and startup support, to appeal to young professionals. Enhancing public services like healthcare and eldercare can also improve the quality of life and reduce population outflow. Finally, the "East-to-West Industrial Relocation" policy should be used to shift labor-intensive industries to the west and northeast, creating jobs, promoting balanced population distribution, and fostering robust domestic and international circulation.

3. The eastern region should leverage the dual-circulation strategy to drive technological innovation and green economy growth, continuing to attract top talent and innovative enterprises, accelerating industrial upgrading, and optimizing population quality. Through

digital economy and innovation policies, the east can further strengthen its economic competitiveness. The central region should deepen industrial collaboration with the east, promote industrial transfer and innovation, enhance infrastructure, and cultivate domestic markets to attract a larger inflow of people. The west, with its abundant green energy and digital transition opportunities, should implement targeted industrial policies to attract talent and capital for high-quality economic growth. It can also expand economic partnerships through the Belt and Road Initiative to foster regional economic synergy. Meanwhile, the northeast should accelerate industrial transformation by supporting smart manufacturing and technology-driven industries, fostering talent retention, and enhancing local population quality. These policies collectively support balanced high-quality population development across regions, linking domestic and international circulation and promoting coordinated regional growth.

4. Facilitating rational population mobility and labor market innovation is key. The eastern region should strengthen management and services for incoming populations to prevent resource overconcentration and urban issues. The central and western regions need to improve their industrial chains and urban amenities to attract returning populations and talent. Encouraging city clusters to collaborate across eastern, central, and western regions can promote balanced development, with policies that support inter-regional movement of businesses and people, foster cross-regional industry chains, and drive high-value industrial transformation in the west and northeast. This approach aims to enhance quality of life and ensure stable, fulfilling livelihoods for people across regions.

Acknowledgments

This paper is supported by the National Social Science Fund of China (Western Project No. 21XSH014) and the Gansu Province Science and Technology Program (Soft Science Project No. 22JR4ZA054).

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