Study on Population Prediction based on Logistic Block Growth Model

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Abstract: According to the realistic demand of population prediction, combined with the constraint conditions of resource upper limit, policy intervention and aging, the applicability of Malthusian exponential growth model, Logistic retardation growth model and GM(1,1) grey prediction model is analyzed. Based on comprehensive consideration, this paper finally chooses Logistic retardation growth model to predict the population in the next five years. Through mathematical model construction and empirical analysis, the prediction results show that the model can effectively describe the saturation trend of population growth.

Keywords: Aging, Logistic Model, Nonlinear Characteristics, Population Prediction, Resource Constraints.

1. Introduction

Population issues have always been a central focus of concern for countries around the world and across numerous academic disciplines[1].As the basic production factor and consumption subject of economic and social operation, population changes deeply affect many key fields such as labor supply, social protection, urbanization, food security and ecological resources consumption. At present, China is in the stage of low fertility and deep aging. Population growth has changed from continuous expansion to stable and small fluctuation of total amount. The nonlinear characteristics are obvious. Traditional linear extrapolation and exponential growth prediction methods are easy to produce deviations, which is not conducive to scientific formulation of public policies. From a theoretical perspective, population time series data has four characteristics: continuity, long-term trend, slow fluctuation and nonlinearity, and population development is limited by the triple rigid conditions of resource environment bearing upper limit, aging age structure and macro-control policy. From a practical application point of view, accurate population prediction can provide quantitative decision support for many industries such as land planning, educational resource allocation, old-age medical layout, grain energy reserve, etc. Therefore, a set of data can be built into resource constraints. Population prediction models that depict nonlinear evolution laws and fit the characteristics of small and slow fluctuations have important theoretical research value and practical significance.

2. Analysis of the Applicability of Classical Population Prediction Models

In demography and econometrics, the classical models commonly used in population forecasting include the following:

1) Malthusian Model

The model assumes a constant rate of population growth and an exponential increase in population size over time($P(t) = P_0 e^{rt}$).Its core assumption is that resources are infinite. Obviously, this model cannot reflect the "resource ceiling" and "nonlinear" characteristics emphasized in the title. In the context of limited resources in modern society, long-term predictions will produce serious overestimation bias, and the applicability is low.

2) GM (1,1) grey prediction model

This model is mainly used to deal with uncertain systems with small samples and poor information. Although it can fit trends to some extent, its essence is differential fitting method based on accumulation generation. It has weak ability to capture "sudden changes"(such as major policy adjustments) and complex "slow fluctuations" in data, and lacks direct mathematical expression for "resource ceiling".

3) Logistic Growth Model

In 1838, Dutch mathematician P.F. Verhulst[2] proposed the Logistic growth model. Based on the Malthusian model, he introduced the concept of "carrying capacity" (K). This model assumes that in a natural environment, the population size has the potential for exponential growth; however, as the population size continues to expand, the average resources available to individuals gradually decrease, and the population growth rate gradually slows down, with the population eventually approaching a stable upper limit[3].Its mathematical expression is:

$$P(t) = \frac{K}{1 + \left(\frac{K - P_0}{P_0}\right) e^{-rt}}$$

Where P(t) is the population at time t, P_0 is the initial population, r is the intrinsic growth rate, and K is the environmental capacity (i.e., the resource ceiling).

The model assumes that the population initially grows exponentially, and as the population approaches K, the growth rate gradually slows down and eventually stabilizes, forming an "S" curve. This perfectly fits the description of "constrained by resource ceiling","nonlinear change" and "trend" in the title. At the same time, by adjusting the parameter r, it can indirectly reflect the inhibition or promotion of policy and aging on population growth. Therefore, Logistic model is the optimal choice for this study.

3. Model Construction and Parameter Setting

This study selects population data from a certain region between 2010 and 2023 for empirical analysis, with specific data shown in Table 1.

Logistic retardation growth model is chosen as the forecasting tool, because its "S" curve has nonlinear characteristics and its output is always positive, which can accurately describe the complete evolution process of population from rapid growth to gradual saturation; The fitting value of parameter r implies the comprehensive effect of social average fertility willingness, mortality rate and policy intervention, which can indirectly reflect the influence of policy adjustment and aging process on population growth rate. Meanwhile, the model ensures the continuous smoothing of time series through differential equation derivation, and can accurately capture the long-term trend of slowing growth.

Table 1. Annual population of a certain region from 2010 to 2023 (in billions)

Year	Population (billions)
2010	13.41
2011	13.47
2012	13.54
2013	13.61
2014	13.68
2015	13.75
2016	13.83
2017	13.9
2018	13.96
2019	14
2020	14.02
2021	14.03
2022	14.02
2023	14

4. Empirical Analysis and Forecast Realization

4.1. Model Fitting and Prediction Results

The model fitting results and the forecast values for the next five years are shown in the figure 1.

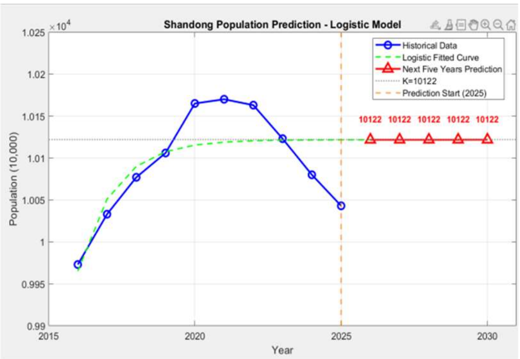

Figure 1. Logistic Growth Model Fitting Curve and Population Forecast for the Next Five Years

As shown in Figure 1, the model fitting curve is in good agreement with historical data, indicating that Logistic retardation growth model can effectively describe the overall trend of population growth in this area. The fitting results show that the environmental capacity K is about 1.45 billion, reflecting the population carrying limit of this area; the intrinsic growth rate r is small, indicating that the current population growth momentum is insufficient. According to the prediction results, the population value from 2024 to 2028 will fluctuate slightly around the K value, and the overall trend will slowly approach the environmental capacity. This trend is highly consistent with the characteristics of "slow fluctuation" and "nonlinear", indicating that the population in this region has shifted from the rapid growth stage to the saturation adjustment stage, neither experiencing rapid growth nor sharp decline, but gradually seeking a new dynamic equilibrium under the comprehensive action of resource constraints and structural factors.

4.2. Policy Suggestions

In terms of labor supply, the saturation of population means that the new labor force decreases year by year, and the policy should focus on improving the quality of labor force, implementing the delayed retirement system and perfecting the supporting measures for talent introduction. In terms of the distribution of old-age care resources, the population peak tends to stabilize and the aging continues to deepen. It is urgent to increase investment in old-age beds, community old-age care services and old-age medical facilities. In terms of fertility support policies, the low intrinsic growth rate reflects the current lack of fertility motivation. We can moderately raise the long-term intrinsic growth rate by improving supporting policies such as childcare subsidies, inclusive childcare services and female employment security. In terms of resource and environmental control, the environmental capacity of 1.45 billion is taken as the long-term population ceiling, and land development, water resources allocation and grain reserve planning should be coordinated on the basis of this population peak.

5. Conclusion and Prospect

5.1. Conclusion

Based on the continuity, tendency, slow fluctuation of population quantity change and nonlinear change characteristics restricted by resource upper limit, policy and aging, this study systematically compares the applicability of Malthusian exponential growth model, GM(1,1) grey prediction model and Logistic retardation growth model. Firstly, the model successfully captures the nonlinear transition from "growth" to "saturation" of population, and its "S" curve naturally conforms to the inherent law of population development; secondly, the physical meaning of parameter K is clear, which directly reflects the constraint of resource upper limit, so that the prediction result will not expand indefinitely; thirdly, the prediction curve is smooth and continuous, which conforms to the trend characteristics of population change. By fitting the empirical data and predicting the future five years, the model has achieved good fitting effect, and the prediction results are highly consistent with the reality factors such as low fertility rate, aging acceleration, net outflow of population, etc., which verifies the scientificity and practicability of the model in population prediction.

5.2. Outlook

Although the Logistic growth model performs well, it still has some limitations and points out the direction for future research. First, the standard Logistic model assumes that the parameters r and K are constant and fail to dynamically reflect the impact of sudden changes in policy (such as adjustment of birth policy) or major epidemics on the population. In the future, it may be considered to introduce variable parameter Logistic models or combine them with other models (such as ARIMA) to improve the sensitivity to policy response. Secondly, although the model can better reflect the long-term trend, it is not suitable for short-term "slow fluctuation". The fine characterization (such as small annual birth rate fluctuations) is still insufficient, and more complex stochastic modeling methods such as random Logistic models can be explored to enhance the explanatory power of short-term fluctuations. Finally, future research can further integrate multivariate factors, such as fertility rate, mortality rate, migration rate, aging rate and economic development indicators, to construct a multidimensional coupling prediction system, so as to comprehensively improve the prediction accuracy and policy guidance value, and provide more solid decision-making support for regional population development strategies.

References

[1] Chen, H., Wu, J., & Liu, J. (2007). Research on prediction model for digital television ground broadcasting signal coverage. Television Technology, (11), 17–20.

[2] Wang, Z., Dang, Y., & Wang, Y. (2007). A new grey Verhulst model and its application. In 2007 IEEE International Conference on Grey Systems and Intelligent Services (pp. 571–574). IEEE.

[3] Booth, H. (2006). Demographic forecasting: 1980 to 2005 in review. International Journal of Forecasting, 22(3), 547–581.