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RESEARCH ON THE EFFECTS OF FERTILITY POLICY ON POPULATION STRUCTURE IN CHINA

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ABSTRACT

In order to optimize the population structure facing the country, many countries have introduced fertility policies, but the effects of the fertility policy on the population structure is abstract. The purpose of this paper is to quantify the fertility policy on population structure by using Bayesian theorem and Leslie model, especially the impact of population aging. Firstly, based on the historical data and the Bayesian formula, the policy adjustment multiplier is obtained to determine the fertility rate of each age under different fertility policies, thereby predicting the total population size and population structure under different fertility policies. Then, taking the China as an example, a comparative analysis of the total population and population structure of China under the "Universal Two-Child" policy and "separate" policy in 2020-2030. Finally, the results show that the influence of the birth policy on the population structure has a certain role, but it takes a long time to be effective and cannot fundamentally solve the population problem.

Keywords: Bayesian theorem, Fertility policy, Leslie model, Policy adjustment multiplier, Population structure.

1. INTRODUCTION

Population size and population structure are important factors that influence social development and affect the sustainable development of economy and society. (Zhu et al.2016). And the rationality of the population structure has a certain influence on the political and economic stability of the country (Leahy, 2007). At present, many countries face various demographic problems, and most of them have adopted the fertility policy to adjust the irrational population structure of country, such as "Two-Child" policy in China, "Eugenic Protection" law in Japan,

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and "Basic Plan for Low Fertility and Aging Society" in Korea. The impact of the fertility policy on population size and structure effect the fertility rate of women in all ages mainly by affecting fertility desires and reproductive behaviors of women of child-bearing age, so that, the policies can indirectly affect the population size and structure of the future. However, the impact of birth policies on fertility desires and fertility behavior is abstract. The magnitude of the impact of policies on population size and structure and whether the fertility policy can truly achieve the goal of optimizing the population structure are worthy of us to study.

At present, various scholars have studied the impact of fertility policy, but few has quantified the effects of the fertility policy in fertility rate and predicted the change of population structure under different fertility policy. D'Ercole (2005) pointed out that fertility policy is the trends and determinants of fertility rate. Wu (2018) established the necessity assessment indicators system for fertility policy reform and assessed the need for reform of the fertility policy in each province in China. A Ouedraogo（2018）examined the relationship between the fertility and fertility trend, and found that there is significant negative correlation between the fertility rate and anti-fertility policy. Cheng (2016) studied the change of women's childbearing desire and women's rights and interests under the implementation of "two-child" policy. Walker (1995) used the neoclassical economic framework to analyze the effects of Sweden's economic and policy environment to fertility patterns.

In the study of total population size and population structure prediction, most of the literature is based on historical or survey data for analysis and prediction. J Grant (2004) established a framework to study the interrelationship between the government policies macro-level and the household level affecting population factors and predicted the trend of the European population change. Li (2014) analyzed the types and fertility status of child-bearing age couples under the new Chinese policy through sample surveys and progressive levels to predict the future Chinese population structure and proposed that policies have a positive effect on optimizing the population structure. Zhai (2016; 2017) predicted the future changes in China's population under the new policy by using the queuing factor method and PADIS-INT population forecast software. Grant (2004), based on European population trend survey data, studied the relationship between policies and population trends and behavior in European and believed that policies can prevent or mitigate the adverse effects of fertility rates and population ageing. The limitation of these literature is that the existing literature failed to establish mathematical model to compare the total population size and population structure under different policies.

To sum up, scholars have seldom quantified the influence of fertility policies on fertility rates to study the changes in population structure under different policies and assess the extent of new fertility policies to population structural problems. In view of this, we introduce policy

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adjustment multipliers to quantify the impact of fertility, predict and compare the change of population size and structure under different policies, and analysis the effects of the new fertility policy in China on population issues in relation to population aging.

The rest of the paper is constructed in following three sections. In the next section "Establishment of a population forecasting model", the policy adjustment multiplier is obtained and the change in fertility rates under different policies is determined through the distribution of fertility differential variables and the expectation equations and the Leslie model is established to predict the population size and structure of the future. Followed by "Case study", we apply the model to study an example, compare and analyze the results of the two scenarios, and derive the effect of fertility policy on population structure. The final section concludes the paper.

2. ESTABLISHMENT OF A POPULATION FORECASTING MODEL

As fertility policies change the fertility rate through the influence of fertility desires and fertility behaviors, they indirectly affect the total population. Although fertility is not equal to fertility, the two are highly relevant. Therefore, this section first studies fertility desires and fertility behaviors, and sets distributions of fertility will and fertility differential variables, thereby exploring the differences in the distribution of these variables, to better perform regression analysis.

Because the impact of the new policy on the total population is mainly due to the changes in the fertility desire of women of childbearing age, the adjustment multiplier is introduced to quantify the impact of policies on fertility, among which, the adjustment multipliers represent the rate of the change in fertility under different policies.

Since the adjustment multiplier has a certain correlation with the fertility difference, this paper will solve the policy adjustment multiplier by the differential distribution of fertility variables and the expectation equation, and then determine the value of fertility ratio under different policies. Finally, the Leslie model is combined to predict changes in population and structure under different policies.

2.1 Determination of Expectation Differences in Fertility Willingness

When the difference between fertility intention and fertility behavior is taken as an explanatory variable, and various influencing factors are taken as explanatory variables, the distribution of interpreted variables is in accordance with a normal distribution (Rang, 2015). Because when the number of children that woman desire is less than she is currently raising, the explanatory variable is negative, and in this time, the explanatory variable is meaningless. Therefore, before

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the regression, all the negative explanatory variables should be adjusted to zero, and at this time, the distribution is changed into the Poisson distribution. By using Poisson regression, the model is:

$$P(Y_i = y_i \mid x_i) = \frac{e^{-\lambda_1} \lambda_i^{y_i}}{y_i!} (y_i = 0, 1, 2 \cdots) \quad ....(1)$$

Among them, y is the difference between fertility desire and fertility behavior, x_i is the influencing factor, including age, education, marital status and family size (Rang, 2015).

2.2 Establishment of Probability Model of Fertility Rate Prediction

Formula for fertility r_i (Wang, 2004；Xu, 1986):

$$r_i = \frac{CWB_i}{CW_i} \quad ....(2)$$

Among them, CWB_i represents the total number of children born when women is an the age of i , CW_i represents the total number of women of age i.

Probability model for the number of children regenerated by the woman of childbearing age of i age (Rang, 2015):

$$E(CN_i) = E_i \left[E_i \ (LBDIF \mid AHP) \right] \quad ...(3)$$

Among them, CN_i indicates the number of children regenerated by the woman of childbearing age of i age, $LBDIF$ represents the number of children that gave birth by women who have legally willing at the age of 30 i , AHP indicates the realization of fertility desires and policies. When there is no new policy and other external interventions, the fertility desire can be considered as constant (Feng et al, 2002). We assume that all women follow the birth policy, and the formula of $LBDIF$ is:

$$LBDIF = \min(BDIF, LLNC - ENC) \quad ...(4)$$

In the formula (5), *BDIF* is the difference between the ideal number of children and the number of existing children for family, *LLNC* indicates that the maximum number of children can be born under the constraints of the policy, *ENC* is the number of children in a family. Among them, the negative value of *BDIF* actual value should be adjusted to zero.

In order to simplify the model, the willingness to fertility under different policies is independent of the difference between fertility intentions of women of childbearing age under different policies and the number of existing children. In combination with the Bayesian total probability formula, $E(CN_i)$ is as follow:

$$E(CN_i) = P(AH)E_i(LBDIF \mid Policy) \qquad \text{...(5)}$$

Among them, *AH* means that fertility will be achieved.

2.3 Determination of fertility under the new policy

The adjustment multiplier formula for the new policy to obtain the fertility rate is:

$$k_{i,new} = \frac{f_{i,new}}{f_{i,old}} . \qquad \text{...(6)}$$

Among them, $f_{i,old}$ represents the average fertility rate of women of childbearing age at age i in the original policy, which can be obtained from historical data; $f_{i,new}$ indicates the fertility rate under the new policy. Therefore, the solution to $f_{i,new}$ is transformed into the adjustment multiplier $k_{i,new}$ under the new policy, the formula is as follows:

$$k_{i,new} = \frac{E_i(LBDIF \mid new)}{E_i(LBDIF \mid old)} \qquad \text{...(7)}$$

After calculating the adjustment multiplier of all ages for women, the expected fertility rate under the new policy can be obtained according to the formula (6). Then, the change of population under the new policy can be predicted.

2.4 Population Prediction by Age Group Based on Leslie Model

(1). Population prediction model based on Leslie

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Step1: Age group and discrete time length determination:

The age of the population is divided into 90 age groups according to size. Each age group is 1 year old and is recorded as:

$$i = 1,2,3...,90$$

Since the length of time is equal to the age group interval, each year is set as a time period, which is recorded as:

$$t = 1,2,3...,90$$

Step2: Relationship between the total number of people in year t+1 and age i in year t

The population of the 1st age group in the t+1 year is the sum of the number of births in the t th year, while the total population of the i age group in the previous year survived the i+1th of the t+1 year.

The population of the age group, so k_i (t), and k_i (t+1) should satisfy the relationship:

$$\begin{cases} k_1(t+1) = \sum_{i=1}^{m} r_i k_1(t) \\ k_{i+1}(t+1) = s_i k_i(t), i = 1, 2, \cdots, m-1 \end{cases} \quad ...(9)$$

Assuming that the reproduction rate and survival rate do not change with time, so that both s_i and d_i are constant

Step3: Introduce fertility mode h_i

$$r_i(t) = \beta(t) h_i \quad \left(\sum_{i=i_1}^{i_2} h_2 = 1\right) \quad ...(10)$$

$$k_1(t+1) = \beta(t) \sum_{i=1}^{m} h_i k_1(t) \quad ...(11)$$

Stept4: Introducing age-grouped population distribution vectors

$$k(2011)=\left[k_1(t),k_2(t),\ldots,k_n(t)\right]^T \quad \ldots(12)$$

Stept5: Construct the Leslie matrix and substitute the above data

$$A=\begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ s_1 & 0 & \cdots & 0 & 0 \\ 0 & s_2 & \cdots & 0 & 0 \\ \vdots & \vdots & & \vdots & 0 \\ 0 & 0 & \cdots & s_{n-1} & 0 \end{bmatrix}, \quad B=\begin{bmatrix} 0 & \cdots & 0 & r_{i_1} & \cdots & r_{i_2} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & & \vdots & \vdots & & \vdots & \vdots & & \vdots \\ 0 & \cdots & 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \end{bmatrix}$$

Stept5: Determination of the total population in year $t+1$

$$n_1(t+1)=Ax(t+1)+\beta(t)\mathbf{n}_1(t) \quad \ldots(13)$$

(2). Determination of fertility mode

In the Leslie model, fertility model h_i is an important indicator for determining the prediction accuracy of the Leslie model and the future forecast value, At the same time, the fertility model h_i is influenced by $k_{i,new}$, Therefore, the fertility model h_i can be calculated by $k_{i,new}$, so that we can determine the parameters of the Leslie model. The fertility model here refers to the fertility weighting factor for females whose age is *i*, and it has nothing to do with time in a stable environment. At the same time, the fertility pattern h_i obeys the chi-square distribution, so the following formula is derived:

$$h_i(k)=\frac{(i-i_1)^{\alpha-1}e^{-\frac{i-i_1}{\theta}}}{\theta^{\alpha}\Gamma(\alpha)}, i>i_i \quad \ldots(14)$$

Among them $\theta=2, \alpha=n'/2, i_c=i_1+n-2$ indicates the age at the highest fertility rate, i_i indicates legal marriage age, *n* reflect reproductive age index of women of childbearing age. Figure 2 shows the general standard fertility model h_i .

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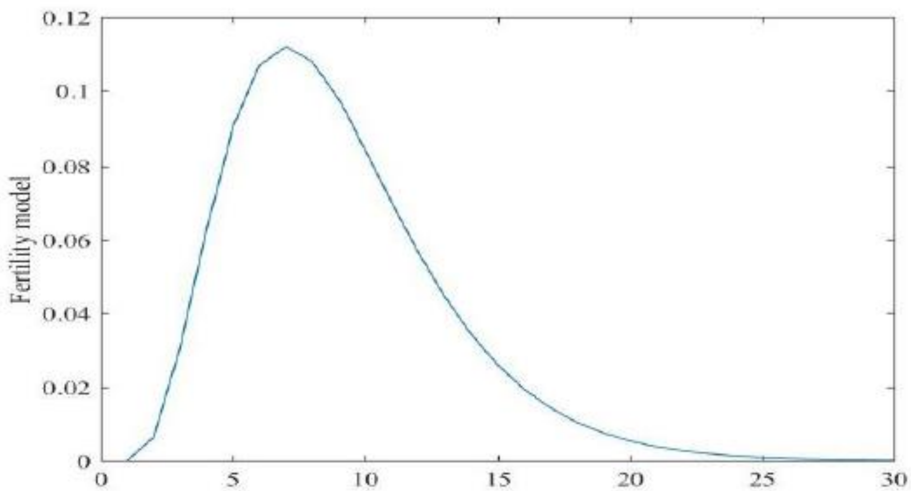

Figure 2: The map of birth model distribution map

3. CASE STUDY

3.1 solving process

We take China as an example to predict the total population and population structure under the introduction of new fertility policy named the Universal Two-Child policy (represented as *CSCP*) and study the effects of the new policy to population structure by comparing with the old policy named the Two-Child Fertility policy (represented as *SSCP*) which is for couples where either the husband or the wife is from a single-child family.

Then, to calculate $E_i(LBDIF \mid policy)$ in formula (5) and (7), the conditional distribution of *LBDIF* should be calculated based on the Bayesian formula. In the absence of premarital pregnancy, the specific calculation process is as follows:

(1). Two-Child Fertility policy

Under the implementation of this policy, it can be considered as the Universal Two-Child policy for eligible women of child-bearing age, while other women implement family-planning policies. Among them, under the family planning policy (represented as *OCP*), since the maximum number of children allowed under the policy is 1, the value of the LBDIF may be 0 or 1.

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$$P[LBDIF_i = 0] = 1 - P[LBDIF_i = 1] \quad (15)$$

$$P[LBDIF_i = 1] = P[BDIF_i \geq 1, \ ENC_i = 0] = P[BDIF_i \geq 1] \times P[ENC_i = 0] \quad (16)$$

Under the family planning conditions, $LBDIF$ expectations to be:

$$E_i[LBDIF_i \mid OCP] = 0 \times P[LBDIF_i = 0] + 1 \times P[LBDIF_i = 1] \quad (17)$$

Under the single-child policy, $LBDIF$ expectations for age i to be:

$$E_i[LBDIF \mid SSCP] = (1 - \varphi_i)\, E_i[\mathrm{LBDIF} \mid OCP] + \varphi_i E_i[\mathrm{LBDIF} \mid CSCP] \quad (18)$$

(2). Universal Two-Child policy ($CSCP$)

Under the implementation of this policy, the maximum childbearing value permitted by the policy is 2, then the values corresponding to the LBDIF are 0, 1, and 2. Therefore, under this policy, the probability distribution is:

$$P[LBDIF_i = 2] = P[BDIF_i \geq 2, \ ENC_i = 0] = P[BDIF \geq 2] \times P[ENC_i = 0] \quad (19)$$

$$P[LBDIF_i = 1] = P[BDIF_i = 1, \ ENC_i = 0 or 1] = P[BDIF_i \geq 2] \times P[ENC_i = 0 or 1] \quad (20)$$

$$P[LBDIF_i = 0] = 1 - P[LBDIF_i = 2] - P[LBDIF_i = 1] \quad (21)$$

Therefore, LBDIF expectations to be:

$$E_i[LBDIF \mid CSCP] = 0 \times P[LBDIF_i = 0] + 1 \times P[LBDIF_i = 1] + 2 \times P[LBDIF_i = 2] \quad (22)$$

Thus, to $E_i\,(LBDIF \mid \ policy)$, suppose that the people's own legal awareness is high, and the number of children expected to have an ideal child is in line with the current national policies and regulations, and the formula of it is as follows:

$$\begin{cases} P[LBDIF_i = 2] = P[BDIF = 2] \\ P[LBDIF_i = 1] = P[BDIF = 1] \\ P[LBDIF_i = 0] = 1 - P[LBDIF_i = 2] - P[LBDIF_i = 1] \\ E_i[LBDIF \mid CSCP] = P[LBDIF_i = 1] + 2 \times P[LBDIF_i = 2] \end{cases} \quad (23)$$

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In summary, the solution to $k_{i,new}$ based on the policies in China is as follows:

$$k_{i,new} = \frac{E_i(LBDIF \mid CSCP)}{E_i(LBDIF \mid SSCP)}$$

$$s.t.\begin{cases} E(BDIF) = P(x_i) \\ P[LBDIF_i = j] = P[BDIF = j](j = 0,1,2) \\ E_i[LBDIF \mid CSCP] = \sum_{j=0}^{2} j * P[LBDIF_i = j] \end{cases}$$

Among them, $E_i = (LBDIF \mid SSCP)$ is an unbiased estimate based on the mean of historical data as its mathematical expectation; *P (xi)* represents the expectation formula for the difference in fertility intention after Poisson regression between the influencing factor x_i and the difference in fertility desire and fertility behavior.

3.2 Annual Population Forecast in China

Based on the data of China National Bureau of Statistics website and China Statistical Yearbook, the prediction result of the future total population under two policies in China is as follow:

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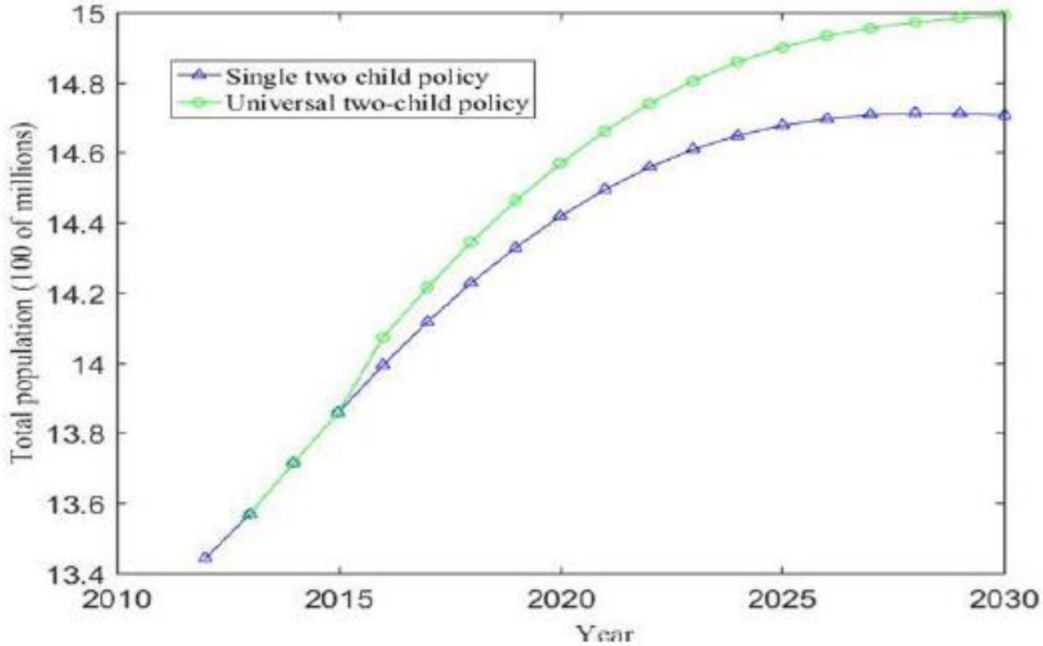

Figure 3: Total population under the two policies in 2012-2030

Among them, "Universal Two-Child" policy is issued in 2015, so, the value of "two-child fertility" policy in 2012-2015 we use is actual. As can be seen from Fig 3, in 2012-2015, the forecasted value (green) is in good agreement with the actual value (blue).

3.3 China's Annual Population Structure Forecast

(1). Forecast of the ratio of labor force to non-labor population

According to the United Nations World Health Organization's criteria for age classification, the newly issued regulations of the Chinese government, and the total number of people of all ages in China in 2011, combined with the Leslie model, the result of the ratio of labor force to non-labor force population in 2020- 2030 is shown in Fig. 4:

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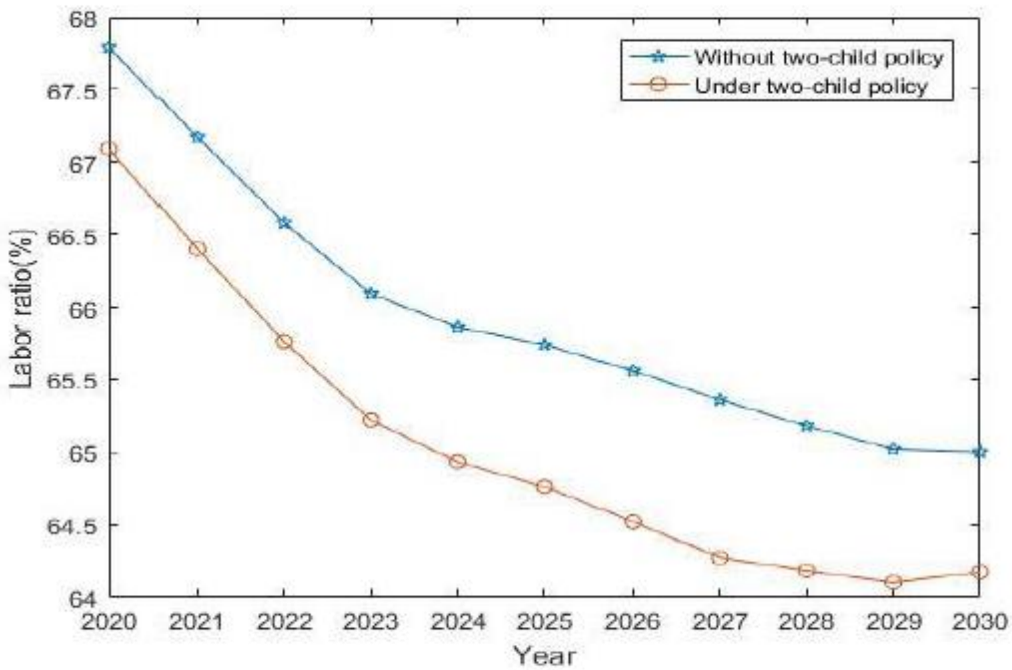

Figure 4: Chinese labor force in 2020-2030 under two policies

Based on the Fig. 4, regardless of the implementation of the Universal Two-Child policy, Chinese labor ratio shows a downward trend, and under the implementation of the Two-Child policy, the decline in the labor ratio is faster than the implementation of the policy, and the gap increases year by year. Since the increase in the non-labor ratio under the Universal Two-Child policy means the increase in the total population of the elderly and children, the following section will be made on the non-labor population in order to further study the impact of the Universal Two-Child policy on the fertility rate and aging population in China.

(2). Prediction of Age Distribution of Chinese Population under "Universal Two-Child" Policy

According to the total number of people of all ages in China in 2011, the results of the age distribution of Chinese population in the future 2020-2030 are shown in the following Table 2:

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Table 2: Age distribution of 2020-2030 Cense population

Age / Year	0~14	15~64	>65
2020	294850108	977416009	184581632
2021	301155384	973514273	191356096
2022	306196481	969227674	198487060
2023	309184148	965531669	205792664
2024	311255523	964825879	209779468
2025	312716682	964938503	212370854
2026	316170308	963429376	21359437
2027	318242778	961246722	216033319
2028	30840375	960942199	227824837
2029	298098556	960428602	239776377
2030	287921145	961933050	249197669

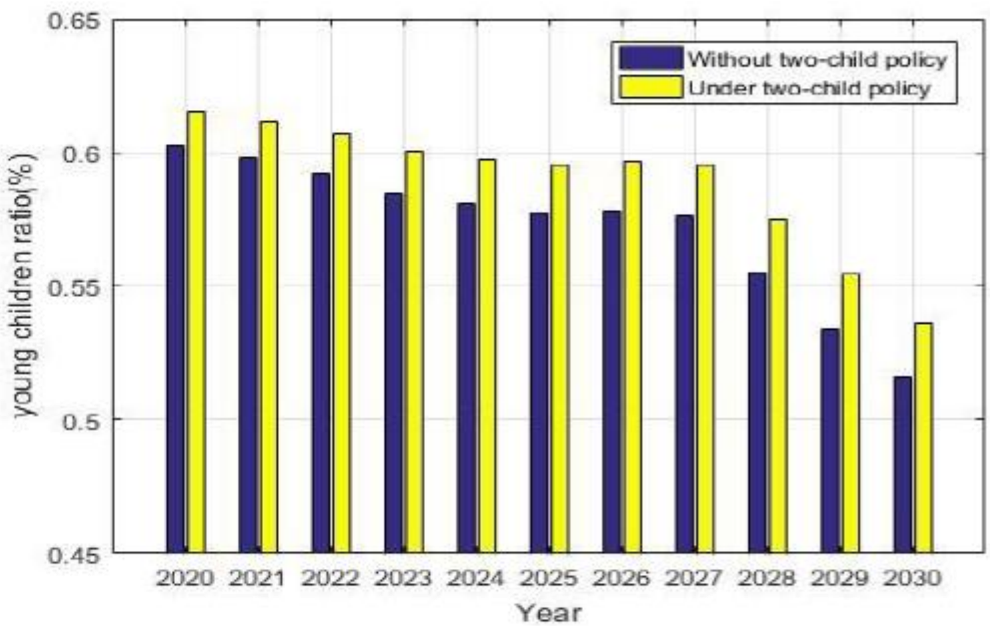

Figure 5: The proportion of children in the non-labor population in 2020-2030

From Table 4, it can be seen that, due to the implementation of the Universal Two-Child policy, the number of young children's population has gradually increased for a period of time, and then fell back, which Hejun Gu (2018) got the same conclusion. Besides, the elderly population is in the trend of increasing, the aging of the population still exists and remains severe. With reference to

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Table 4 and Fig. 5, under the "Universal Two-Child" policy, although the ratio of the non-labor under the Universal Two-Child policy is higher than the other policy during 2020-2030, the children ratio in non-labor in it is higher under the Universal Two-Child policy and the gap between children and elderly ratio increases gradually. This means that, under the Universal Two-Child policy, the fertility ratio increases significantly. And it can be predicted that, in the future, the labor population will gradually increase and the problem of the aging of the population will be relieved though the effect by the new policy is small in the short time.

Besides, based on the Fig.4 and Table 2, we find that, after 2027, the total population gradually becomes stable and the number of children decreases, which may be due to the large population, shortage of resources, and the high dependency ratio. Thus, the Universal Two-Child policy is difficult to fundamentally solve the problem of the aging population but needs a series of policies to support it, Zhu (2016) also got the same conclusion.

4. CONCLUSION

The fertility policy has an impact on the country's population structure and population issues (Li, 1997), and the population structure will affect the national economy (Zhang et al, 2012), but, the impact of fertility policy is abstract. Thus, it is necessary to quantify the effects of fertility policy and predict the future population structure. Then, we put forward the method of quantifying and predicting the effects of the fertility policy on the population structure, combined with the Bayesian, regression analysis and Leslie, and take Chinese fertility policy as an example to study the feasibility of the model and analyze the influence of the policy on the population structure. The current research maintains that, after the implementation of the Universal Two-Child policy, the total population and children ratio increase year by year, but, the problem of population aging has not been better alleviated in a short time. The effects of the Universal Two-Child policy on the aging of the population become more pronounced with time. However, based on the total population in China, the dependency ratio, and shortage of resources, the number of children comes down after a period of time, and Gu Hejun (2018) also proved this. Therefore, the Universal Two-Child policy can alleviate the problem of the Chinese population structure, but it cannot completely solve it, which Zhu (2016) also reached the same conclusion. In order to adjust and optimize the population structure, the state needs to introduce a series of supporting policies and education publicity to ease the problem of China, such as child-raising pressure, shortage of resources, and so on.

Because the migrants and immigrants are not taken into consideration in this paper, the predicted environment is a relatively closed system. Therefore, in the future research, consideration should be given to the migrant population and the immigrant population to better understand the future

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population structure and total population and analyze the effects of the new fertility to population.

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