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Research Paper

The World's Optimal Population Size Forecast

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Abstract: *As is known to all, the population of the world has been increasing, growing especially rapidly over the last two centuries. Further, despite natural disasters and military conflicts, the trend of population growth shows no sign of ceasing anytime soon. Economists have tried to analyze optimal population size from an economic perspective and this paper discusses using an economic model of resources and population to measure the optimal population size of the world and to try to forecast when, barring some cataclysmic event (such as another world war) humanity might reach the optimal population size.*
Key words: *optimal population, economic growth, resources*

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I. Introduction

Malthus was the first economic scholar whose research explored the field of population size. In (Malthus, 1803), the author argued that the pace of population growth and the harnessing of resources cannot continuously match each other, ultimately population growth will outstrip resources. For example, Malthus noted that the population grows exponentially, but the yield of crops grows linearly. Therefore, in the long term, population growth will far exceed the crop yields, leading to great famines.

However, after the Industrial Revolution, the growth rate of output can be calculated as exponential growth. Robert Solow (1956) came up with the model that growth rate of the economy is at a stable rate, and the population will also continue to grow at a stable rate. Dasgupta (1969) adopted notion of optimal population growth that maximization of the total discounted welfare of all generations from now to infinity. Cigno (1981) argued that under exhaustible resource condition, constant population growth rate is implausible. Robert and Becker (1989) designed the model that shows fertility decisions are affected by transfer payments, taxation and initial capital stock. Gary Theodore and Chong (1993) followed endogenous growth to obtain an optimal path with smaller population size and higher output growth rate. Renstrom and Luca Spataro (2011) concluded that under different utilitarianism assumptions, the economy will have different optimal population growth rate. David and Charles (2001) concluded that climate change can affect long-run growth of population under Malthus framework. In recent years' studies, Lawson (2018) has the definition of optimality is when the social welfare gained by adding one more person equals the social cost incurred by adding one more person.

The key to studying the optimal population problem in this article lies in how to define the notion of optimal. In conformity with previous articles on contemporary population models, we can solve for the equilibrium between marginal utility and marginal cost, that is, the utility that can be obtained by adding one person is equal to the marginal cost required by adding one person. However, this article also considers another viewpoint. From the perspective of consumption, combined with the theory of Pareto efficiency, to increase the population of the Earth as much as possible under resource constraints, because increasing the population without reducing per capita utility will obviously increase the total utility of the Earth.

II. The Model

Before introducing the model in this article, we need to make some assumptions. Firstly, we assume that the Earth is a whole. All people on Earth are exactly the same in terms of geographical environment, residential address, and so on.

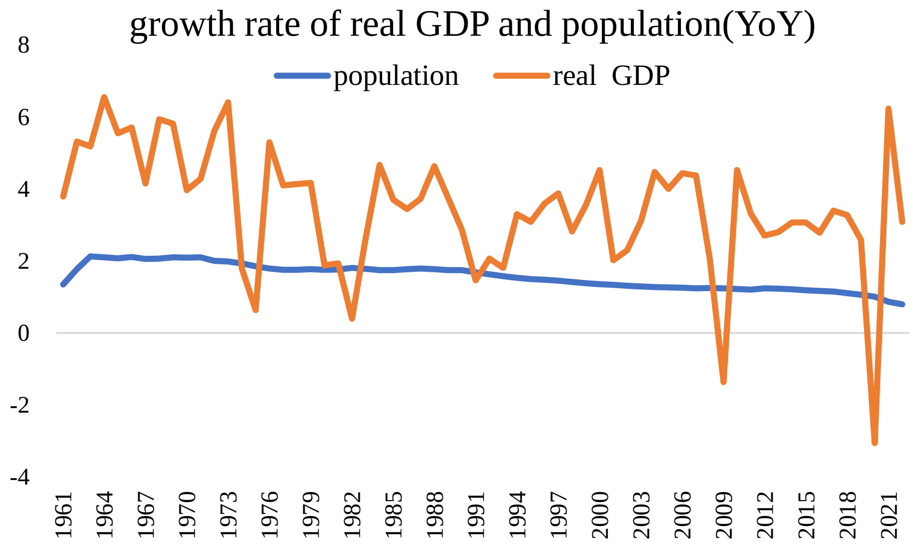
The next step is to write the formulas required for the model in this article, including production functions and resource constraints. Subsequently, we will search for corresponding data based on these formulas and constraints, and then analyze the data to determine the optimal population on Earth and make certain predictions about future population.

First, we write down the production function:

$$F(K, AL) = AK^{\alpha}L^{1-\alpha} \quad (1)$$

The function is consistent with the production function in the Solow model. In Solow model, the population growth rate is exogenous, which is also one of the reasons why the Solow model can solve for steady state. Meanwhile, in the Solow model, the output growth rate per capita is only related to the growth of total factor productivity. Therefore, we need to relax the assumption of exogenous population growth rate and explore the impact of technological progress on global population through data analysis.

Figure 1: Real GDP and Population Growth[1]



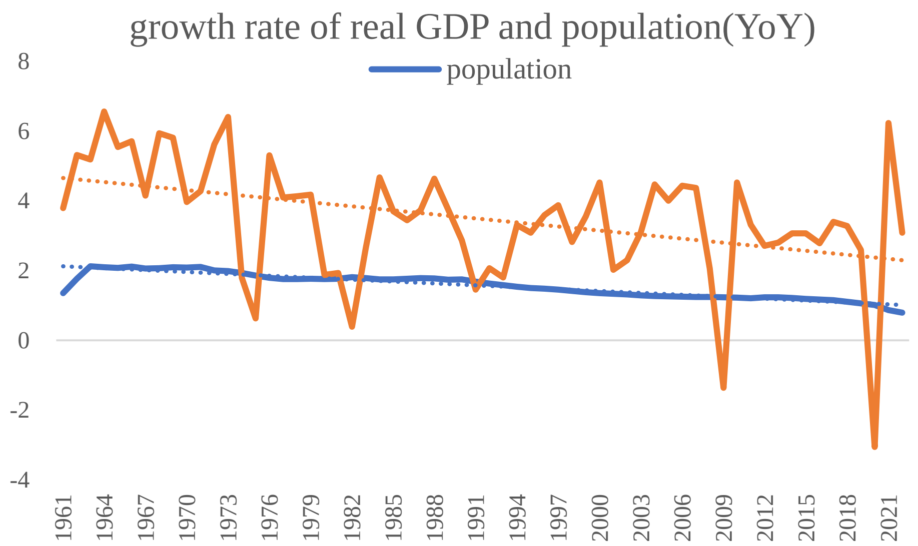
It is not difficult to infer that global per capita output has continued to rise in the past 60 years. Therefore, we can assume that the growth of natural resources increases exponentially every year, rather than the linear increase in Malthusian theory, and the growth rate of per capita resource is even higher.
We can write down the production function of resource goods.

$$F(K_R, A_R L) = A_R\, K_R^{\alpha} L^{1-\alpha} \quad (2)$$

Among them, K_R represents the capital stock of resource products, while A_R represents the total factor productivity of resource production, which is smaller than the total factor productivity of the entire economy. We assume that the production technology content of resource products is smaller than that of industrial products. If the capital stock engaged in resource production, such as land, mines, and other resources, has a growth rate of almost zero, then the increase in resource production only depends on the increase in labor force and total factor productivity.
When the GDP growth rate is higher than the population growth rate, we cannot determine when the Earth is in the optimal population state. In theory, people with such expectations would increase their fertility, but actual data shows that it is not the case.

[1] Source: World Bank

Figure 2: Real GDP and Population Growth with Trend



In Figure 2, we can see the trend lines of global real GDP growth rate and global population growth rate. They both have been in a long-term downward trend in the past 60 years. The decline in population growth rate is very slow, while the decline in real GDP growth rate is relatively large. Therefore, we can speculate that when the global real GDP growth rate and population growth rate are equal, the GDP growth rate per capita is zero, and the world is in the optimal population state. The current global per capita GDP growth rate is still on the rise, and the Earth can accommodate more people to enjoy the dividends of per capita GDP growth.

III. Data Analysis

In this section, we use data provided by the World Bank to calculate when the global real GDP growth rate and population growth rate will converge to the same value. The steps for data analysis are as follows: First, we need to regress the two variables over time. Afterwards, we need to calculate which year they converge to the same value. Finally, we can calculate the steady-state global population size at that time, which is also the optimal population size considered in this essay.

In the descriptive statistics, we can see the time span is from 1961 to 2022. By comparing the mean and variance of population growth rate and real GDP growth rate, we can also find that the mean and variance of population growth rate are smaller than the real GDP growth rate, which conforms with the information in Figure 1. Next, we will perform linear regression on two variables over time to observe their different trends.

Table 1: Descriptive Statistics

Variables	Obs.	Mean	Std. dev	Min	Max
Year	62	1991.5	18.042	1961	2022
Pop_growth	62	1.568	0.354	0.794	2.130
GDP_growth	62	3.475	1.729	-3.058	6.559

By regressing population growth rate and real GDP growth rate, we can find the regression coefficients of both variables are very significant. The regression coefficient of real GDP is -0.039, and the regression coefficient of population growth rate is -0.018, which is about half of the former, indicating the rapid decline of GDP growth rate over time. We calculate the regression results and obtain that the time when the population growth rate equals the real GDP growth rate is approximately 2084. We can conclude that the GDP growth rate and population growth rate at this time are approximately -0.1%. The population on Earth is entering a slow downward phase, but the per capita GDP growth rate is about zero. At this time, the population level on Earth is at its optimal level.

Table 2: Regression Results

Variables	Pop_growth	GDP_growth
Cons	37.83445	80.41641
Coefficient	-0.182	-0.0386
t-value	-19.31	-3.41

P>|t|	0.000	0.001

If we calculate the population growth rate given in the regression equation year by year, by 2084, the global population will grow to about 10.4 billion people, and then decline at a slow rate. This number is relatively in line with economic reality, but it's more likely that the peak of the global population will occur sooner because the downward trend is not linear and is easily disturbed by various exogenous factors.

IV. Conclusions

This article summarizes the history population and economic growth theory and evaluates the reasons why classical theories developed in the 1800's does not match current reality. Afterwards, we referred to research and discussion by contemporary economists on population growth theory, attempting to define what is the optimal population.

We believe that the optimal population size refers to the assumption that the world is a whole, adding one person does not decrease per capita output and resources, and economic growth can nurture more population. In economic terms, when the real GDP growth rate and population growth rate converge to the same value, the per capita GDP growth rate in an economy is zero. If one more person is added to the economy, the per capita GDP will decrease, and social welfare will be damaged. It should be noted that the optimal population size is not necessarily fixed but rather can dynamically change with changes in economic background.

We have linearly regressed the real GDP growth rate and population growth rate over time, and the obtained linear equations can directly determine the intersection point of the two lines, which is the equilibrium point we need to predict. The regression results show that the optimal global population will be reached around 2084, with a population of approximately 10.4 billion people. Afterwards, the population will slowly decline. The analysis in this article is relatively idealistic, and the actual population peak may not reach such a high level because population growth is easily affected by exogenous shocks, and its trend of change is not linear in the long run.

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