Lab -2: Analysis of China's popolation before and after introduction of One-Child Policy

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MC312, Modeling and Simulation

Background

China experienced rapid population growth in the decades after 1949, which led to the introduction of the One-Child Policy in 1980 to slow growth and ease resource pressure. The policy remained in effect until 2015, with significant demographic impacts.

In this lab, we analyze China's population data (1960–2024) using the logistic growth model to estimate growth parameters before and during the policy era. A similar analysis has also been performed for India to compare long-term trends and carrying capacities.

Objectives

- To analyze China's population growth using the logistic equation.
- To estimate growth parameters before and during the One-Child Policy era.
- To compare the carrying capacities and growth rates between different policy scenarios.
- To project long-term population trends.

Model

The logistic growth model is given by:

$$P(t) = \frac{K}{1 + Ae^{-rt}}$$

where:

- $P(t)$ = population at time t,
- r = intrinsic growth rate,
- K = carrying capacity,
- A = constant determined by initial conditions.

Parameter estimation is performed using nonlinear least-squares fitting, minimizing the squared error between observed and predicted populations.

Scenarios

Scenario 1

- Pre-policy period (1960–1979): estimate r_{pre} and K_{pre}.
- Policy period (1980–2024): fix $K = K_{pre}$ and estimate only r_{policy}.

Scenario 2

- Pre-policy period (1960–1979): estimate r_{pre} and K_{pre}.
- Policy period (1980–2024): estimate both r_{policy} and K_{policy}.

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Tasks and Results

(a) Time Series for Scenario 1 & 2

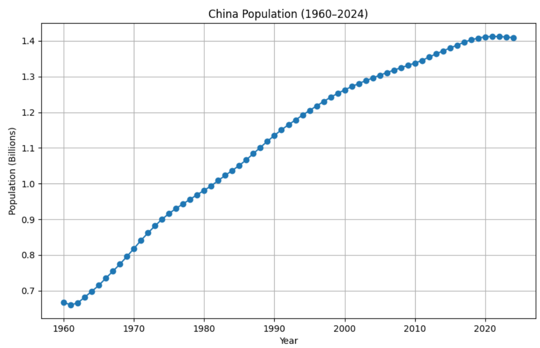

Figure 1: Population of China (1960–2024) with pre-policy (1960–1979) and policy-era (1980–2024) data highlighted for Scenario 1.

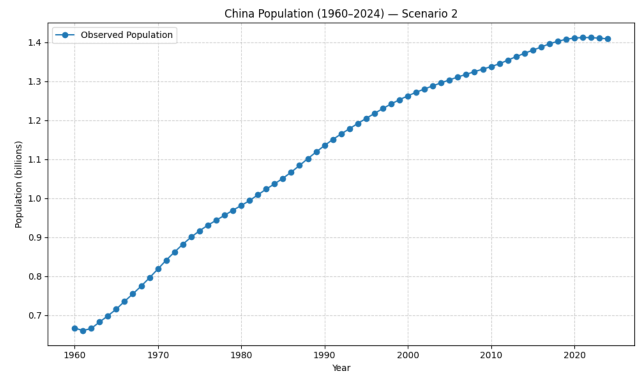

Figure 2: Population of China (1960–2024) used for Scenario 2, where both growth rate and carrying capacity are re-estimated for the policy-era.

(b) Parameter Estimation

- Using nonlinear least-squares fitting:

Case	r (per year)	K (billion)
Pre-policy (1960–1979)	0.041765	1.757
Scenario 1 (Policy era, 1980–2024)	0.031248	1.757
Scenario 2 (Policy era, 1980–2024)	0.049276	1.510

Table 1: Estimated logistic model parameters for China's population growth under different scenarios.

(c) Logistic Curve Fitting

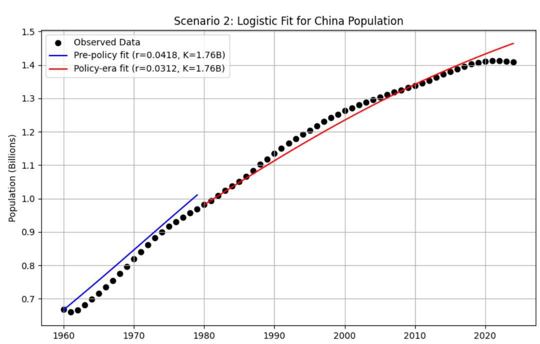

Figure 3: Observed population data (1960–2024) with logistic fits for pre-policy (1960–1979) and policy-era (1980–2024),with the carrying capacity K being constant throughout.

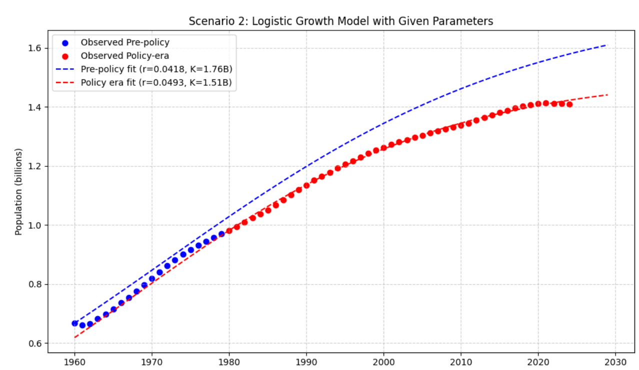

Figure 4: Population of China (1960–2024) used for Scenario 2, where both growth rate and carrying capacity are re-estimated for the policy-era.

(d) Comparison of Growth Rates

The percentage change in growth rate from pre-policy to policy-era is calculated as:

$$\%\Delta r = \frac{r_{policy} - r_{pre}}{r_{pre}} \times 100$$

- Scenario 1:

$$\%\Delta r_1 = \frac{0.031248 - 0.041765}{0.041765} \times 100 \approx -25.2\%$$

- Scenario 2:

$$\%\Delta r_2 = \frac{0.049276 - 0.041765}{0.041765} \times 100 \approx 18.0\%$$

(e) Comparison of Carrying Capacities

The percentage change in carrying capacity is:

$$\%\Delta K = \frac{K_{policy} - K_{pre}}{K_{pre}} \times 100$$

- Scenario 2:

$$\%\Delta K_2 = \frac{1.510 - 1.757}{1.757} \times 100 \approx -14.1\%$$

(f) Projections

Estimate the year when $P(t) = 0.99K$. Show projection plots for each fitted model.

(f) Projections: Year when $P(t) = 0.99K$

The logistic growth equation is:

$$P(t) = \frac{K}{1 + Ae^{-rt}}, \quad A = \frac{K - P_0}{P_0}$$

Solving for t when $P(t) = 0.99K$:

$$t = -\frac{1}{r} \ln \frac{0.0101}{A}$$

Scenario	**Era**	t_{start}	r	K **(B)**	A	**Year** $P = 0.99K$
1	Pre-policy	1960	0.041765	1.757	1.634	2082
1	Policy era	1980	0.031248	1.757	0.791	2119
2	Pre-policy	1960	0.041765	1.757	1.634	2082
2	Policy era	1980	0.049276	1.510	0.539	2061

Table 2: Projected year when population reaches 99% of carrying capacity for each scenario and era.

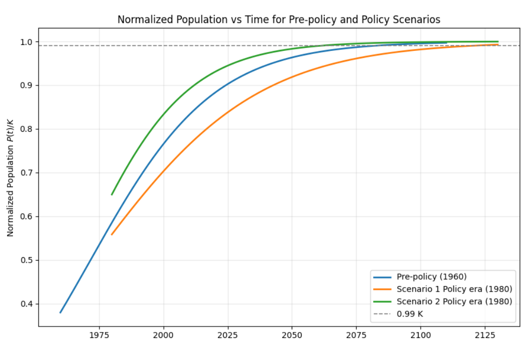

Figure 5: Plot of normalized population vs Years which shows how the $\frac{P(t)}{K}$ approaches $0.99K$ for various models

Insights on r, K, and Stabilization

- A higher growth rate r accelerates how quickly the population approaches $0.99K$. In Scenario 2, despite a reduced K, the larger r leads to near-saturation by 2061, compared to 2119 in Scenario 1 with a slower r.
- The carrying capacity K determines the ultimate population ceiling. A larger K requires more time for the population to reach $0.99K$, whereas a smaller K allows earlier stabilization.
- From a policy perspective, fixing K but lowering r (Scenario 1) delays stabilization, whereas combining a smaller K with a higher r (Scenario 2) causes earlier stabilization but at a lower ceiling, reflecting stricter demographic constraints.

(g) Conclusion and Remarks

1. Effect of Growth Parameters

- The growth rate r governs how fast the population approaches the carrying capacity.
- The carrying capacity K determines the ultimate ceiling; a larger K delays stabilization, while a smaller K brings earlier stabilization.
- Together, r and K determine both the timing and the scale of population stabilization.

2. Scenario-wise Insights

- In Scenario 1, fixing K but lowering r delayed stabilization (reaching $0.99K$ only by 2119).
- In Scenario 2, re-estimating both r and K gave a smaller ceiling but faster stabilization (reaching $0.99K$ by 2061).

3. Policy Implications

- The One-Child Policy was successful in its immediate aim of slowing population growth and achieving earlier stabilization.
- However, this came at the cost of a lower ultimate ceiling and long-term demographic challenges such as an aging population and a shrinking workforce.
- Thus, the policy achieved short-term control over rapid growth but reshaped China's demographic trajectory with lasting consequences.

Extra Credit (Optional)

Perform a similar analysis for India and compare results to China.