Handout for *Kremer (1993)*
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# POPULATION GROWTH AND TECHNOLOGICAL CHANGE: ONE MILLION B.C. TO 1990

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This paper combines the following two findings in the literature:

1. The *size of* population is proportional to the *growth rate of* technology. This is claimed by
   - Kuznets (1960) and Simon (1977,1981) – *A higher population means more potential inventors.*
   - Endogenous growth literature – Aghion and Howitt (1992), Gorssman and Helpman (1991) – *The size of population spurs technological change.*

2. Population is limited by the available technology, so that *growth rate of* population is proportional to the *growth rate of* technology. This is assumed by
   - Malthus (1978) – In the original paper, Malthus (1798) mentions about the state of food production (as technology)

In sum, this paper claims:

**Size of Population ↔ Growth of Technology ↔ Growth of Population**

And by using this, the paper states that the size of population is proportional to the growth of population:

***Size of* Population ↔ *Growth of* Population**

## A SIMPLE MODEL

Assume that the output is given by

$$Y = Ap^{\alpha}T^{1-\alpha} \tag{1}$$

where $A$ is the level of technology, $p$ is the population and $T$ is the land.

After normalizing the land to one[1], at the steady-state, we have

$$\bar{p} = \left(\frac{\bar{y}}{A}\right)^{1/(1-\alpha)} \tag{2}$$

where $\bar{p}$ is the steady state level of population and $\bar{y}$ is the steady state level of per capita income. The growth rate of technology is given by

$$\frac{\dot{A}}{A} = pg \tag{3}$$

where $g$ is the research productivity. Thus, growth rate of technology is proportional to the level of population. Here, we have the assumption that the research productivity is independent of the population size. By taking the logarithm of equation (2), and differentiate with respect to time, we obtain

$$\frac{\dot{p}}{p} = \frac{1}{1-\alpha}\frac{\dot{A}}{A} \tag{4}$$

Therefore, the growth rate of population is proportional to the growth rate of technology. By substituting (3) into (4), we get

$$\frac{\dot{p}}{p} = \frac{g}{1-\alpha}p \tag{5}$$

Here, growth rate of population is proportional to the size of population, as desired[2]. It explains most of the population growth during the history. We can check it by *Figure 1*.[3]

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[1] It is done for simplification, and does not substantially affect the analysis.

[2] Note that, by equation (5), we combined the proportional relationships between *growth rate of technolgy and population size* and *growth rate of technology and growth rate of population,* as promised in the beginning of the paper.

[3] Figure I has been plotted by using the data in Table I.

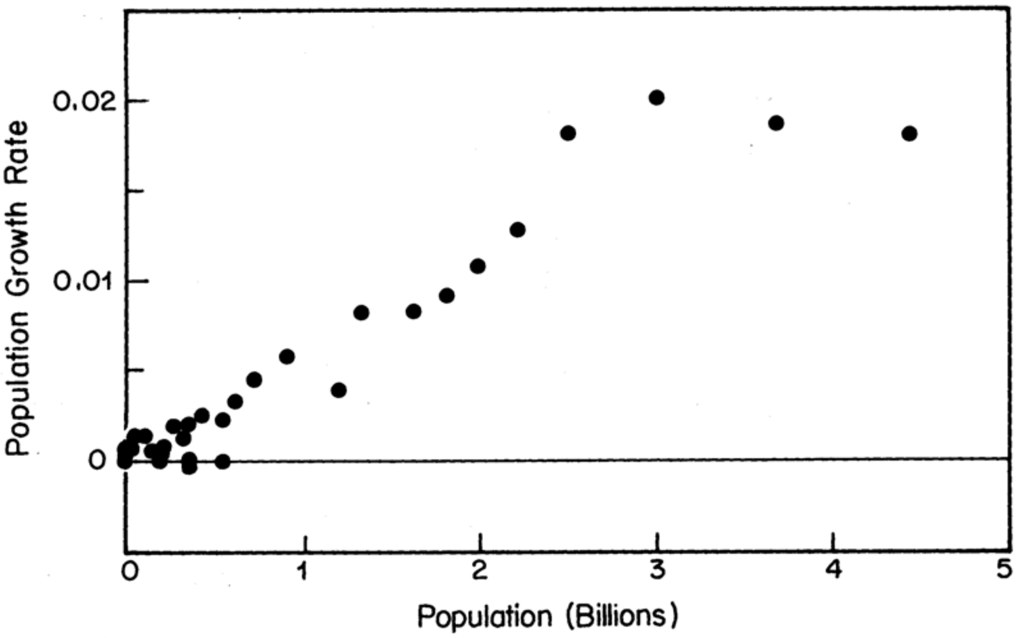


**FIGURE I**
**Population Growth Versus Population**

However, the growth rate of population is faster than an exponential growth, which seems to be unrealistic. Moreover, because of the restrictive assumptions, it does not explain the decline of population growth rates.

## RESTRICTIONS OF THE SIMPLE MODEL

The model cannot explain some features of the contemporary world. Here are the restrictions:

- The model does not allow for some populous countries having low technological levels
- The model does not allow for roughly constant technological change
- The model does not allow for falling population growth rates.
- The model does not allow for rising per capita income levels
- It is assumed that population adjusts to income instantaneously.

$\Longrightarrow$ This simple model has to be generalized.

TABLE I
POPULATION GROWTH: 1,000,000 B.C. TO 1990

| Year | Pop. (millions) | Growth rate | Comments |
|---|---|---|---|
| −1,000,000 | 0.125 | 0.00000297 | |
| −300,000 | 1 | 0.00000439 | |
| −25,000 | 3.34 | 0.000031 | |
| −10,000 | 4 | 0.000045 | |
| −5000 | 5 | 0.000336 | |
| −4000 | 7 | 0.000693 | |
| −3000 | 14 | 0.000657 | |
| −2000 | 27 | 0.000616 | |
| −1000 | 50 | 0.001386 | |
| −500 | 100 | 0.001352 | |
| −200 | 150 | 0.000623 | |
| 1 | 170 | 0.000559 | |
| 200 | 190 | 0.0 | |
| 400 | 190 | 0.000256 | |
| 600 | 200 | 0.000477 | |
| 800 | 220 | 0.000931 | |
| 1000 | 265 | 0.001886 | |
| 1100 | 320 | 0.001178 | |
| 1200 | 360 | 0.0 | Mongol Invasions |
| 1300 | 360 | −0.0002817 | Black Death |
| 1400 | 350 | 0.0019420 | |
| 1500 | 425 | 0.002487 | |
| 1600 | 545 | 0.0 | 30 years war, Ming Collapse |
| 1650 | 545 | 0.002253 | |
| 1700 | 610 | 0.003316 | |
| 1750 | 720 | 0.004463 | |
| 1800 | 900 | 0.005754 | |
| 1850 | 1200 | 0.003964 | |
| 1875 | 1325 | 0.008164 | |
| 1900 | 1625 | 0.008306 | |
| 1920 | 1813 | 0.009164 | |
| 1930 | 1987 | 0.010772 | |
| 1940 | 2213 | 0.012832 | |
| 1950 | 2516 | 0.018226 | |
| 1960 | 3019 | 0.020151 | |
| 1970 | 3693 | 0.018646 | |
| 1980 | 4450 | 0.018101 | |
| 1990 | 5333 | — | |

The growth rate listed for period $t$ is the average growth rate from $t$ to $t + 1$. Since differences of a constant at all times between different data sets would distort growth rates, the 25,000 to 10,000 B.C. growth rate is based on Deevey's population estimates, although the population estimate for 10,000 B.C. is from McEvedy and Jones. Similarly, the 1900–1920 growth rate is based on the 1900–1925 average annual growth rate from McEvedy and Jones. Population figures from 1920 to 1940 and from 1950 to 1980 are from the 1952 and 1985/6 editions of the *United Nations Statistical Yearbook,* respectively. The 1990 population estimate is from the 1991 *World Almanac* [1991], which attributes it to the U. S. Bureau of the Census.

## GENERALIZATIONS OF THE SIMPLE MODEL

**1.** Research Productivity as a Function of Income

- Higher incomes may increase the research productivity per person
- With this extension, it is possible to explain why some populous countries like China or India have comparatively low technology levels

**2.** Research Productivity as a Function of Technology Size

- Higher level of technology may increase the research productivity.
- This model is consistent with both modern and historical data.

**3.** Research Productivity as a Function of Population

- Relax the assumption that research productivity is independent of the size of the population.
- With specific parameters of the model, research productivity may increase with population as suggested by Kuznets (1960), Grossman and Helpman (1991) or Aghion and Howitt (1991).
- At some level, research productivity may decrease with population because of redundant research activities, such as duplicating the same research.

Thus, a generalized version of the research equation is consistent with

$\Rightarrow$ low research productivity in some populous countries.

$\Rightarrow$ the possibility that exogenous increases in population reduce research productivity

$\Rightarrow$ constant growth rates of technology in recent history.

## GENERALIZED FULL MODEL

In this model, the growth rate of technology (research productivity) depends on the technology size, income and on a weighted sum of past population growth rates.

Assumptions:

♦ Population growth is a continuous function of income, n(y).

♦ At zero income, population growth is negative due to high mortality.

♦ At some level of income, population growth is positive (otherwise the human race would have died out)

♦ Population growth decreases with high levels of income[4]

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[4] Because, higher levels of income and technolgy may reduce fertility by increaseing wages (thus the value of time), by increasing education, by changing the pattern of intergenerational transfers, and by increasing the relative value of women's time.

We can summarize the assumptions of the full model in Figure II.

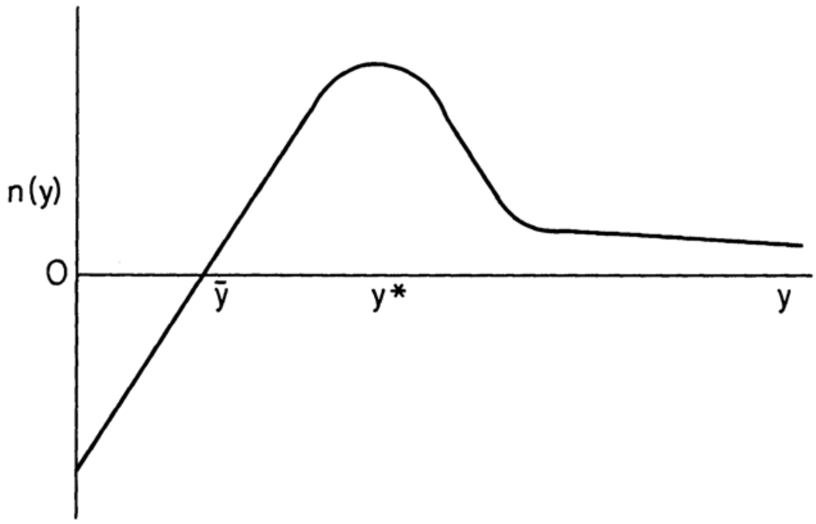


**FIGURE II**
**Population Growth Versus Income**

The dynamic behavior of the model can be analysed by using Figure IV.

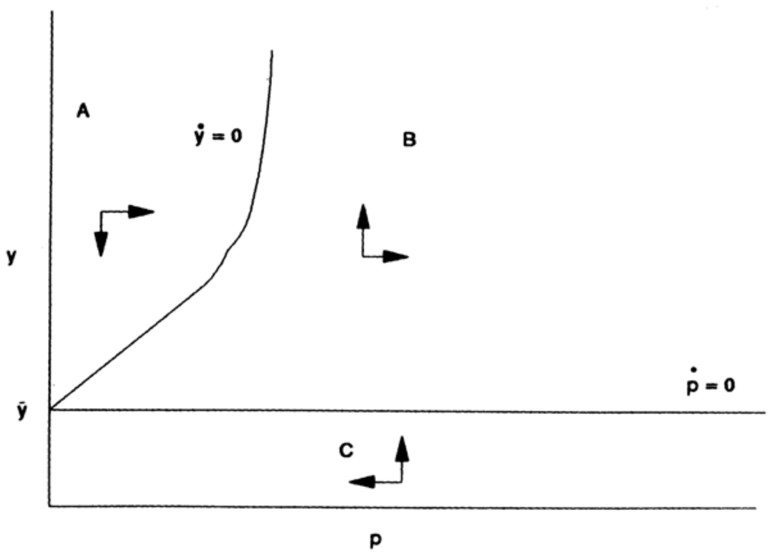


**FIGURE IV**
**Phase Diagram in Population-Income Space**

$\Rightarrow$ No matter where the economy starts, it winds up in region B.

$\Rightarrow$ Once the economy is in region B, income and population grows indefinitely. Thus, income must eventually reach $y^*$, the level above which population growth slows.

## EMPIRICAL RESULTS

➢ Testing the Model with Population Data

The model is tested by using the data in Table I under the null hypothesis that population is limited by technology change that is independent of population. The results strongly reject the null hypothesis that the coefficient on population is zero. Thus, the model is consistent with empirical test results.

➢ Cross-Section Evidence from Technologically Separate Regions

According to the data in 1500, mainly four regions are compared, and as a result, it is found that the technology level and the estimated population density increases with land area, as the model predicts. This evidence is shown in Table VII.

TABLE VII
POPULATION AND POPULATION DENSITY, C. 1500

| | Land area (million km$^2$) | Population c. 1500 (millions) | Population/(km$^2$) |
|---|---|---|---|
| Old World[a] | 83.98 | 407 | 4.85 |
| Americas[b] | 38.43 | 14 | 0.36 |
| Australia[c] | 7.69 | 0.2 | 0.026 |
| Tasmania | 0.068 | 0.0012–0.005 | 0.018–0.074 |
| Flinders Island | 0.0068 | 0.0 | 0.0 |

a. Sub-Saharan Africa is included in the old world, since there was some contact across the Sahara.
b. There are a wide range of population estimates for the Americas and Australia at the time of European arrival, and McEvedy and Jones's are at the low end. However, higher estimates would not affect the rank ordering.
c. Estimates for Tasmania are based on the *Encyclopaedia Brittanica*.

## CONCLUSION

- ➢ According to the integrated model of population growth and technological change of this paper, the growth rate of population is proportional to the level of population.
- ➢ Empirical evidence supports the model.
- ➢ Technological change cannot be independent of population.
- ➢ Rather than concentrating on the negative effects of population growth, the economists should try to measure the growth and welfare effects of population growth.

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