Human Population
2017

Lecture 5
Growth 2
Extrapolation
Demographic Transition
Doomsday growth
Population Models of Extrapolation

What are the assumptions in the UN projections?

How accurate have the extrapolation-based predictions been?

What factors are being ignored by extrapolation?
20th century predictions were accurate

U.N. forecasts of world population in the year 2000 and their percentage error.

SOURCE: Data from various U.N. reports
But the future is uncertain.

Expected error is huge compared to late 20th century predictions.
Methods used for predictions

- **Vital Rates Methods:**
  - Extrapolation of fertility decline, regional.
  - Extrapolation of rise in life expectancy, regional.
  - Migration rates assumed to continue as they are currently. Fertility and life expectancy of migrants partially shift to those of the new region.
  - Projections are determined by Systems Simulations, allowing for short term fluctuations in vital rates.
Lutz-type systems model

Lutz used trends in vitals, migration.

- Fixed rates of migration between regions, based on current values.
- Each region has its own trends in vitals.

Migration rates times population equals Flow, in each direction. Migration creates a locally-negative-feedback loop.
Migration data

- http://migrationsmap.net/

Qualitative, current migration data is found here. Trends in migration are hard to predict...
How good is vitals-extrapolation

• "No changes in migration over 100 years"?
• Birth/death rate trends are inaccurate.
• Carrying capacity is ignored.
US birth rate trend predictions, 1963- have been continually revised downward.

Why is the census bureau overestimating birth rate?
US death rate trend predictions 1963-1994 overestimate deaths

Graph 5. The Observed and Forecasted Crude Death Rates for the Total Population of the United States: 1964 to 1999

[Rate per 1,000 persons]

Why is the census bureau overestimating death rate?

Internet Release Date: November 6, 2002
Predictions of net immigration trends 1964–1999 are consistently too low.

Graph 7. The Observed and Forecasted Crude Net Immigration Rates for the Total Population of the United States: 1964 to 1999

[Rate per 1,000 persons]

Observed

Why is the census bureau underestimating migration?

Internet Release Date: November 6, 2002
3 Questions posed by the authors in the book "BEYOND SIX BILLION"

- Can the fertility declines that are now under way in many developing countries be expected to continue at a rapid pace?
- What are the socioeconomic and other factors that determine the speed of decline?
- Is replacement fertility likely to prevail in most countries in the long run, or could fertility remain higher or lower than replacement level for long periods?
birth/death rate trend model

Here is a way to generate predictions of population using trends in vitals.

- Converts time to birth/death rate using historical trends.

Converters can be used to construct trends, which can be the results of other models.
Trends in vitals with economic development: 
Demographic Transition Theory

As countries become industrialized, the death rate first drops, followed by the decreased birth rate.

Gap between birth rate and death rate determines rate of natural population increase. Gap is higher for developing countries. Why?

Developed country

DT is modest.

Less developed country

DT is extreme.
Demographic Transition Model

In **Stage 1**, which applied to most of the world before the Industrial Revolution, both birth rates and death rates are high. As a result, population size remains fairly constant but can have major swings with events such as wars or pandemics.

In **Stage 2**, the introduction of modern medicine lowers death rates, especially among children, while birth rates remain high; the result is rapid population growth. Many of the least developed countries today are in Stage 2.

In **Stage 3**, birth rates gradually decrease, usually as a result of improved economic conditions, an increase in women's status, and access to contraception. Population growth continues, but at a lower rate. Most developing countries are in Stage 3.

In **Stage 4**, birth and death rates are both low, stabilizing the population. These countries tend to have stronger economies, higher levels of education, better healthcare, a higher proportion of working women, and a fertility rate hovering around two children per woman. Most developed countries are in Stage 4.

In **Stage 5** fertility rates have fallen significantly below replacement level (2 children) and the elderly population is greater than the youthful population. Sweden, Germany, Japan are in Stage 5.
Dropping fertility

USA Fertility Rates by Race, 1980 to 2010

<table>
<thead>
<tr>
<th>Years</th>
<th>TFR</th>
<th>Years</th>
<th>TFR</th>
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<tr>
<td>1975–1980</td>
<td>3.83</td>
<td>2025–2030</td>
<td>2.21</td>
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<td>1980–1985</td>
<td>3.61</td>
<td>2030–2035</td>
<td>2.15</td>
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<tr>
<td>1985–1990</td>
<td>3.43</td>
<td>2035–2040</td>
<td>2.1</td>
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<td>1990–1995</td>
<td>3.08</td>
<td>2040–2045</td>
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<td>1995–2000</td>
<td>2.82</td>
<td>2045–2050</td>
<td>2.02</td>
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</table>


Technical Note: The Hispanic category begins only in 1988. "White Non-Hispanic" TFR figures for 1980-1985 are not reported. The "White" category includes "White-Hispanic". This is done based on the observation that in the 1960s, "White non-Hispanic" TFRs were consistently 90%-91% of the "White" figure itself, i.e. the "White" category was inflated by high fertility of Hispanics enough to cause a substantial rise in apparent TFR. This TFR-inflation will necessarily be reduced in the future, but one hopes, as Hispanics were born in number in 1980 than today. CDC data puts the figure at 91.7% in 1988. To obtain the numbers here for 1980-89, it is assumed that the figure for "White non-Hispanic" started at 93% the "White" figure in 1950, falling to 91% in 1960. In the 10 years of 1969-1978, "White non-Hispanic" TFR averaged 91.4% of the "White" figure. By the early 2000s, it was ~90%. ... Black figures here are also "Non-Hispanic Black" from 1989, but do include some "Black Hispanics" before that, which do not dramatically alter Black TFRs. [http://www.fertility.org]
Will falling fertility solve the population problem?
Why does the death rate go down?

- cultural --
  - science!
  - better sewer systems, sanitary practices
  - medicine, safety
  - better law enforcement

- environmental --
  - elimination of disease carrying insects
  - improved agricultural technology
  - more energy?
Why did the birth rate go down?

- **cultural** -- Demographic Transition Model
  - education leads to planning ahead
  - more affluence, better health, less infant mortality
  - less agrarian, less need for young labor force

- **environmental** --
  - cost of non-renewables goes up, therefore food costs increase, therefore can't afford children
  - pollution increases death rate
  - crowding leads to increased violence, not a good environment for kids
  - water scarcity leads to decreased food
To what do we owe falling fertility?

• Descriptive task:
  - Falling fertility with increased education/affluence/industrialization is almost universal.
  - Fertility anti-correlates with life expectancy.

• Interpretive task:
  - Seems like transition from r-selected to K-selected species!
Fertility anticorrelates with life expectancy
Fertility transition

- People that live in dangerous places are like species with low survival rates. These species have many offspring and don't take care of them. Danger, not shortages, controls population. r-selected.

- People that live in safe places compete with each other for resources, have fewer children and give them every possible advantage. Resource shortages, not danger, limit population. K-selected.

Is it instinct? Or reason? Or both?
Model 2. Von Foerster equation: Doomsday growth

\[
\frac{dN}{dt} = \left( \alpha_0 N^{1/k} \right) N
\]

Growth rate is a monotonically increasing function of \( N \)

Integrating yields:

\[
N_t = N_1 \left( \frac{t_0 - t_1}{t_0 - t} \right)^k
\]

\( t_0 \) is doomsday, 13 Nov 2026

Von Foerster equation

\[
\frac{dN}{dt} = \left( \alpha_0 N^{1/k} \right) N
\]

Growth is proportional to the number of people, because births and deaths are both proportional to number of people.

This additional term says that growth rate (the difference between birth rate and death rate) increases with population. This is not generally true for living organisms. But it fits the data.
The Doomsday equation fits historical global population data up to 1960

$$N_t = N_1 \left( \frac{t_0 - t_1}{t_0 - t} \right)^k$$

Log-log plot of historical human population versus time (lower x-axis) and dooms-time (upper x-axis). The fit is hyperbolic!

Reasons for positive feedback, *hyperbolic* growth: How does population increase boost life expectancy and fertility?

- Increased specialization.
- Less fighting.
- Technology improves.
- Competition with other species decreases.
- Knowledge increases.
Discuss

Coalitions

However, what may be true for elements which, because of lack of adequate communication among each other, have to resort to a competitive, (almost) zero-sum multiperson game may be false for elements that possess a system of communication which enables them to form coalitions until all elements are so strongly linked that the population as a whole can be considered from a game-theoretical point of view as a single person playing a two-person game with nature as its opponent. In this situation it is not absurd to assume that an increase in elements may produce a more versatile and effective coalition and thus not only may render environmental hazards less effective but also may improve the living conditions beyond those found in a "natural setting."
Does per capita GDP increase explain hyperbolic growth?

World Average GDP Per Capita
1500 - 2000 C.E. (log scale)

State-based violence has been decreasing.

Evidence of the increasing one-ness of all humanity?
Doomsday scenario

Based on the principle of "the bigger they are, the harder they fall..."
As overshoot approaches infinity, what happens to the severity of the inevitable collapse?

Minimum viable population = population at which there is a 90-95% chance of survival 100-1000 years into the future. MVP is higher for K-selected species.
In view of this uncomfortable picture it is clear that, while the pessimists, one way or another, are “Malthusians by profession,” the optimists must be “Malthusians at heart,” hoping that at some time, somehow, something will happen that will stop this ever-faster race to self-destruction.
Global population continued to track the Doomsday Equation until 1999.


Fig. 1. World population $N$ (left scale) and world population density $n$ in elements per square mile (right scale) observed (circles), calculated after Eq. 11 (solid line) and projected by different authors (triangles) as a function of historical time $t$ (bottom scale), and of Doomsday $\tau$ (top scale). The numbers associated with each point are references.
The coming singularity in world population: “regime shift”


What might regime shift be?

Pick one

(a) People get smarter, seeing the writing on the wall, have dramatically fewer children.

(b) Nature fights back, the carrying capacity is decreased, dramatically lower life expectancy.
Regime shift (a) People get smarter, seeing the writing on the wall, have dramatically fewer children.

Global trends in Total fertility rate (TFR) = children per woman

Von Foerster estimated we would have to cut fertility by a factor of two from 1960 levels by now. In fact, we did. Was it enough?
Drought helped cause Syria’s war. Will climate change bring more like it?

- By Brad Plumer, Washington Post, September 10, 2013 at 9:34 am

“We looked at the period between 2006 and 2011 that preceded the outbreak of the revolt that started in Daraa. During that time, up to 60 percent of Syria's land experienced one of the worst long-term droughts in modern history. This drought — combined with the mismanagement of natural resources by [Syrian President Bashar] Assad, who subsidized water-intensive crops like wheat and cotton farming and promoted bad irrigation techniques — led to significant devastation. According to updated numbers, the drought displaced 1.5 million people within Syria.”

Civil unrest correlates with food prices.

**Regime shift** (b) Nature fights back, the carrying capacity is decreased, dramatically lower life expectancy.

FIG. 1: Time dependence of FAO Food Price Index from January 2004 to May 2011. Red dashed vertical lines correspond to beginning dates of “food riots” and protests associated with the major recent unrest in North Africa and the Middle East. The overall death toll is reported in parentheses. Blue vertical line indicates the date, December 13, 2010, on which we submitted a report to the U.S. government, warning of the link between food prices, social unrest and political instability [56]. Inset shows FAO Food Price Index from 1990 to 2011.
Will there be a Doomsday?

1. Late-stage hyperbolic growth is impossible.
2. Von Foerster inserted jokes, so he wasn't entirely serious.
3. Regime shift idea applies anyway.
Model 3. Logistic growth

\[ \frac{dN}{dt} = (\alpha_0 - \alpha_1 N)N \]

Demographic Transition Theory: Death rate decreases due to industrialization. Then birth rate decreases until the birth rate matches the death rate, at which point the population stabilizes.

Limits to Growth: The environment exerts increasing pressure as population approaches carrying capacity, leading to lower birth rate and high death rate, until rates are equal and population stabilizes.
A Converter takes Variables and applies a function to them, outputting a value.
• **Homework 2** will be to make a model for Demographic Transition Theory
• Use converters to model the dependence of birth/death rates on time.
• Model Japan, Mexico.
• Model 0: linear growth
• Model 1: Exponential growth
  – Extrapolation method
  – sources of error
  – Demographic Transition
    – falling death rate, falling fertility
• Model 2: Doomsday equation
  – Coalitions
  – Collapse
  – Regime change
    – Adaptation
    – Nature fights back
• Model 3: Logistic growth
  – to be continued.