



The End of Economic Growth? Unintended Consequences of a Declining Population

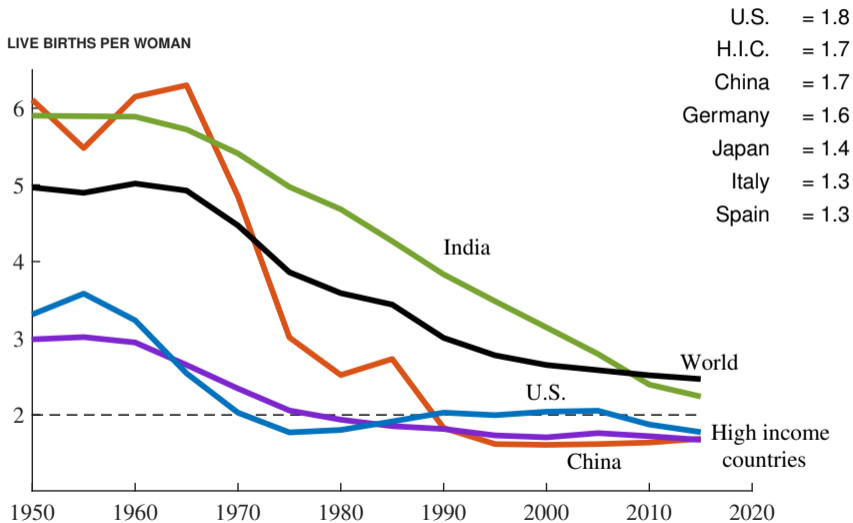
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Key Role of Population

- People \Rightarrow ideas \Rightarrow economic growth
 - Romer (1990), Aghion-Howitt (1992), Grossman-Helpman
 - Jones (1995), Kortum (1997), Segerstrom (1998)
 - And most idea-driven growth models
- The future of global population?
 - Conventional view: stabilize at 8 or 10 billion
- Bricker and Ibbotson's *Empty Planet* (2019)
 - Maybe the future is **negative population growth**
 - High income countries already have fertility **below** replacement!

The Total Fertility Rate (Live Births per Woman)



What happens to economic growth if population growth is negative?

- Exogenous population decline
 - **Empty Planet Result**: Living standards stagnate as population vanishes!
 - Contrast with standard **Expanding Cosmos** result: exponential growth for an exponentially growing population
- Endogenous fertility
 - Parameterize so that the equilibrium features negative population growth
 - A planner who prefers **Expanding Cosmos** can get trapped in an **Empty Planet** – if society delays implementing the optimal allocation

Literature Review

- Many models of fertility and growth (but not $n < 0$)
 - Too many papers to fit on this slide!
- Falling population growth and declining dynamism
 - Krugman (1979) and Melitz (2003) are semi-endogenous growth models
 - Karahan-Pugsley-Sahin (2019), Hopenhayn-Neira-Singhania (2019), Engbom (2019), Peters-Walsh (2019)
- Negative population growth
 - Feyrer-Sacerdote-Stern (2008) and changing status of women
 - Christiaans (2011), Sasaki-Hoshida (2017), Sasaki (2019a,b) consider capital, land, and CES
 - Detroit? Or world in 25,000 BCE?



The Empty Planet Result

A Simplified Romer/AH/GH Model

Production of goods (IRS)

$$Y_t = A_t^\sigma N_t$$

Production of ideas

$$\frac{\dot{A}_t}{A_t} = \alpha N_t$$

Constant population

$$N_t = N$$

- Income per person: levels and growth

$$y_t \equiv Y_t/N_t = A_t^\sigma$$

$$\frac{\dot{y}_t}{y_t} = \sigma \frac{\dot{A}_t}{A_t} = \sigma \alpha N$$

- Exponential growth with a constant population
 - But population growth means exploding growth? (Semi-endogenous fix)

Negative Population Growth in Romer/AH/GH

Production of goods (IRS)

$$Y_t = A_t^\sigma N_t$$

Production of ideas

$$\frac{\dot{A}_t}{A_t} = \alpha N_t$$

Exogenous population decline

$$N_t = N_0 e^{-\eta t}$$

- Combining the 2nd and 3rd equations (note $\eta > 0$)

$$\frac{\dot{A}_t}{A_t} = \alpha N_0 e^{-\eta t}$$

- This equation is easily integrated...

The Empty Planet Result in Romer/GH/AH

- The stock of knowledge A_t is given by

$$\log A_t = \log A_0 + \frac{g_{A0}}{\eta} (1 - e^{-\eta t})$$

where g_{A0} is the initial growth rate of A

- A_t and $y_t \equiv Y_t/N_t$ converge to constant values A^* and y^* :

$$A^* = A_0 \exp\left(\frac{g_{A0}}{\eta}\right)$$

$$y^* = y_0 \exp\left(\frac{g_{y0}}{\eta}\right)$$

- **Empty Planet Result:** Living standards stagnate as the population vanishes!

Semi-Endogenous Growth

Production of goods (IRS)

$$Y_t = A_t^\sigma N_t$$

Production of ideas

$$\frac{\dot{A}_t}{A_t} = \alpha N_t^\lambda A_t^{-\beta}$$

Exogenous population growth

$$N_t = N_0 e^{nt}, \quad n > 0$$

- Income per person: levels and growth

$$y_t = A_t^\sigma \quad \text{and} \quad A_t^* \propto N_t^{\lambda/\beta}$$

$$g_y^* = \gamma n, \quad \text{where} \quad \gamma \equiv \lambda\sigma/\beta$$

- Expanding Cosmos:** Exponential income growth for growing population

Negative Population Growth in the Semi-Endogenous Setting

Production of goods (IRS)

$$Y_t = A_t^\sigma N_t$$

Production of ideas

$$\frac{\dot{A}_t}{A_t} = \alpha N_t^\lambda A_t^{-\beta}$$

Exogenous population decline

$$N_t = N_0 e^{-\eta t}$$

- Combining the 2nd and 3rd equations:

$$\frac{\dot{A}_t}{A_t} = \alpha N_0^\lambda e^{-\lambda \eta t} A_t^{-\beta}$$

- Also easily integrated...

The Empty Planet in a Semi-Endogenous Framework

- The stock of knowledge A_t is given by

$$A_t = A_0 \left(1 + \frac{\beta g_{A0}}{\lambda \eta} (1 - e^{-\lambda \eta t}) \right)^{1/\beta}$$

- Let $\gamma \equiv \lambda \sigma / \beta =$ overall degree of increasing returns to scale.
- Both A_t and income per person $y_t \equiv Y_t / N_t$ converge to constant values A^* and y^* :

$$A^* = A_0 \left(1 + \frac{\beta g_{A0}}{\lambda \eta} \right)^{1/\beta}$$

$$y^* = y_0 \left(1 + \frac{g_{y0}}{\gamma \eta} \right)^{\gamma/\lambda}$$

First Key Result: The Empty Planet

- Fertility has trended down: 5, 4, 3, 2, and less in rich countries
 - For a family, nothing special about “above 2” vs “below 2”
- But macroeconomics makes this distinction critical!
 - Negative population growth may condemn us to stagnation on an **Empty Planet**
 - Stagnating living standards for a population that vanishes
 - Vs. the exponential growth in income and population of an **Expanding Cosmos**



Endogenous Fertility

The Economic Environment

ℓ = time having kids instead of producing goods

Final output

$$Y_t = A_t^\sigma (1 - \ell_t) N_t$$

Population growth

$$\frac{\dot{N}_t}{N_t} = n_t = b(\ell_t) - \delta$$

Fertility

$$b(\ell_t) = \bar{b} \ell_t$$

Ideas

$$\frac{\dot{A}_t}{A_t} = N_t^\lambda A_t^{-\beta}$$

Generation 0 utility

$$U_0 = \int_0^\infty e^{-\rho t} u(c_t, \tilde{N}_t) dt, \quad \tilde{N}_t \equiv N_t / N_0$$

Flow utility

$$u(c_t, \tilde{N}_t) = \log c_t + \epsilon \log \tilde{N}_t$$

Consumption

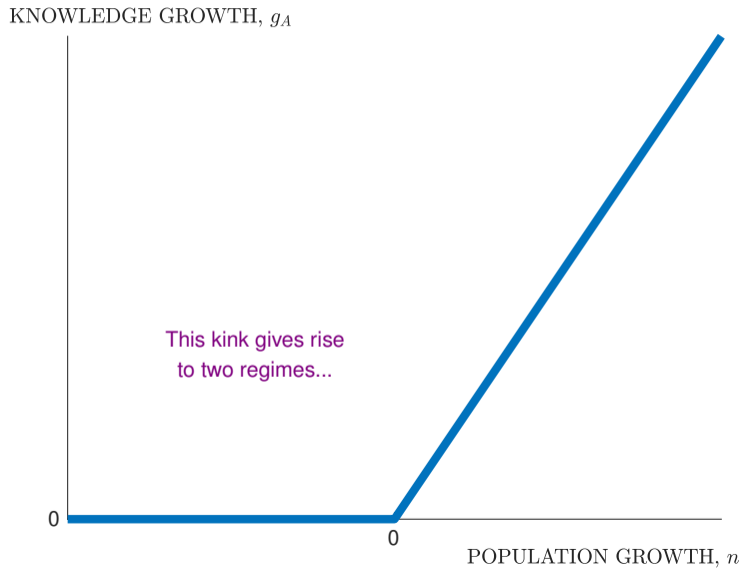
$$c_t = Y_t / N_t$$

(Paper considers generalized Barro-Becker preferences)

Overview of Endogenous Fertility Setup

- All people generate ideas here
 - Learning by doing vs separate R&D
- Equilibrium: ideas are an externality (simple)
 - We have kids because we like them
 - We ignore that they might create ideas that benefit everyone
 - Planner will desire **higher** fertility
- This is a modeling choice — other results are possible
- Abstract from the demographic transition. Focus on where it settles

Steady State Knowledge Growth



Key Features of the Equilibrium and Optimal Allocations

- Fertility in both

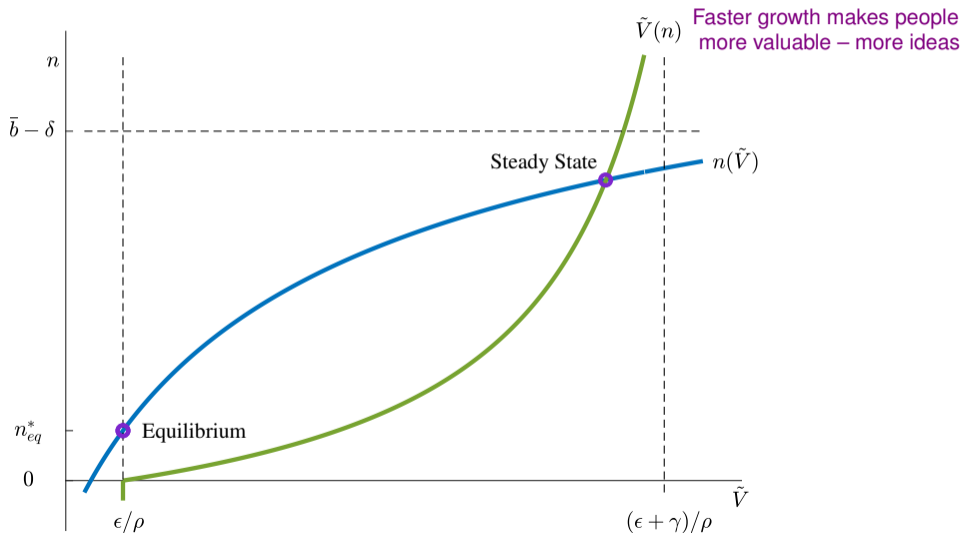
$$n = \bar{b}\ell - \delta$$
$$\ell = 1 - \frac{1}{\bar{b}\tilde{V}}$$

where V is the “utility value of people” (eqm vs optimal). Therefore

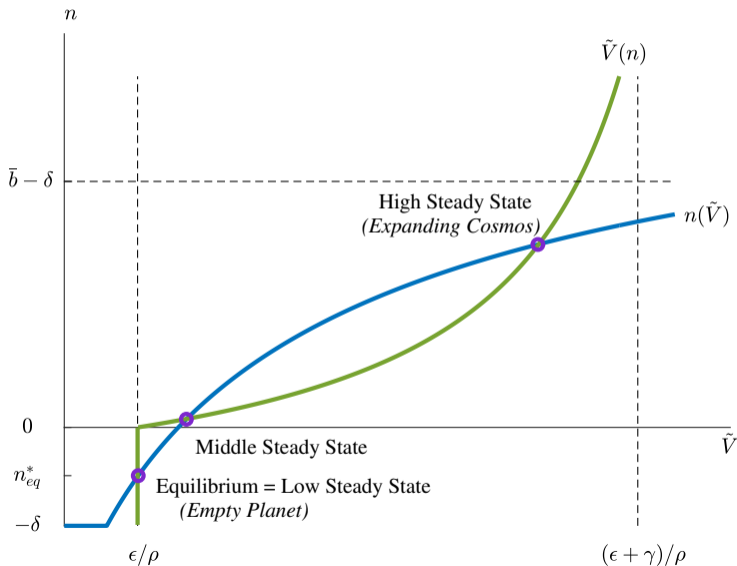
$$n(V) = \bar{b} - \delta - \frac{1}{\tilde{V}}$$

- Equilibrium: value kids because we love them (only): $\tilde{V}^{eqm} = \frac{\epsilon}{\rho}$
 - We can support $n < 0$ as an equilibrium for some parameter values
- Planner also values the **ideas** our kids will produce: $\tilde{V}^{sp} = \frac{\epsilon + \mu\dot{A}}{\rho} \Rightarrow \tilde{V}(n)$

A Unique Steady State for the Optimal Allocation when $n_{eq}^* > 0$



Multiple Steady State Solutions when $n_{eq}^* < 0$



Transition Dynamics

- State variables: N_t and A_t
- Redefine “state-like” variables for transition dynamics solution: N_t and

$$x_t \equiv A_t^\beta / N_t^\lambda = \text{“Knowledge per person”}$$

- Why?

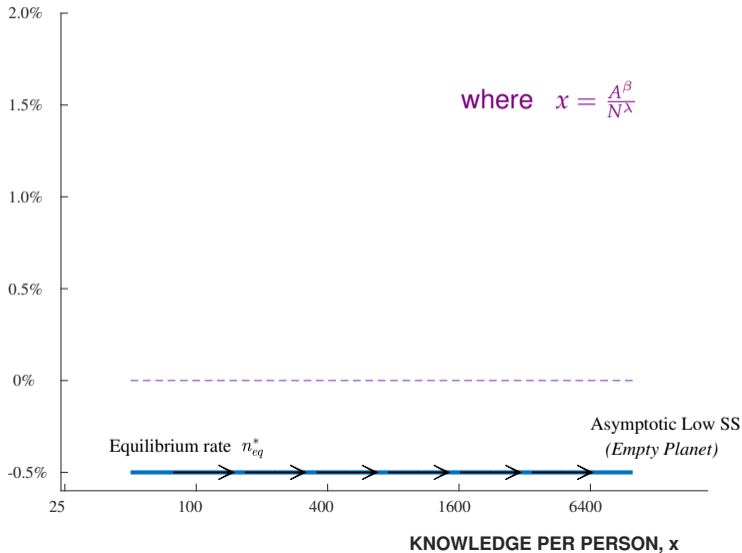
$$\frac{\dot{A}_t}{A_t} = \frac{N_t^\lambda}{A_t^\beta} = \frac{1}{x_t}$$

Key insight: optimal fertility only depends on x_t

- Note: x is the ratio of A and N , two stocks that are each good for welfare.
 - So a bigger x is not necessarily welfare improving.

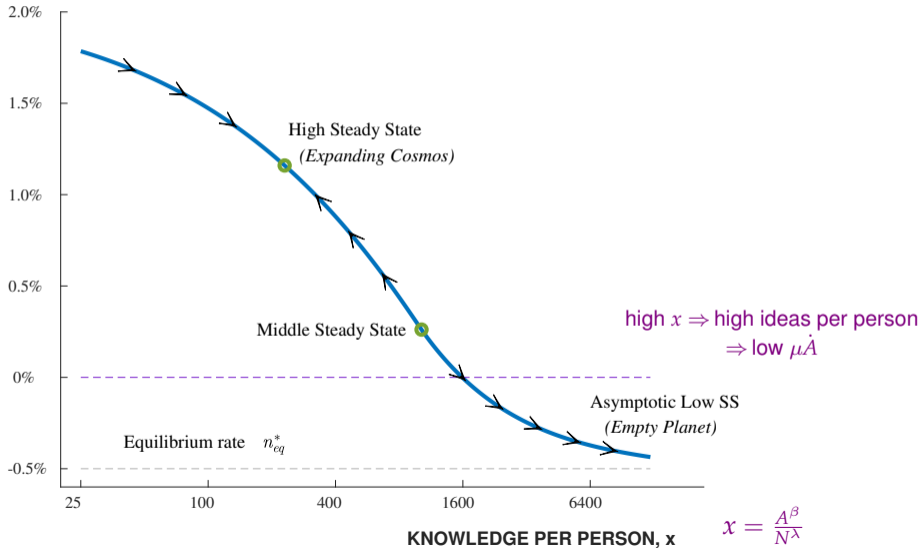
Equilibrium Transition Dynamics

POPULATION GROWTH, $n(x)$



Optimal Population Growth

POPULATION GROWTH, $n(x)$



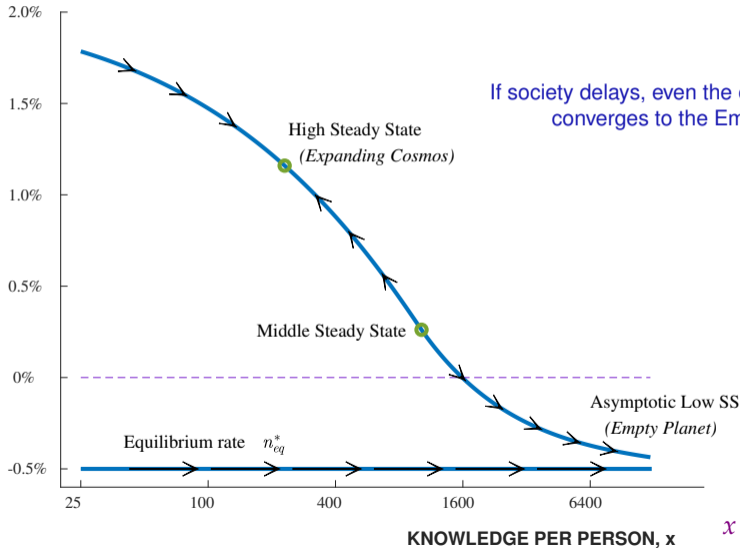
Surprising Result

- The optimal allocation features *two* very different steady states
 - One is an **Expanding Cosmos**
 - One is the **Empty Planet**
- Start the economy with low x
 - The equilibrium converges to the Empty Planet steady state
 - If society adopts optimal policy soon, it goes to the Expanding Cosmos

But if society delays, even the optimal allocation converges to the Empty Planet

Even the optimal allocation can get trapped

POPULATION GROWTH, $n(x)$



$$x = \frac{A^\beta}{N^\lambda}$$

Conclusion

- Fertility considerations may be more important than we thought:
 - Negative population growth may condemn us to stagnation on an **Empty Planet**
 - Vs. the exponential growth in income and population of an **Expanding Cosmos**
- This is not a **prediction** but rather a study of one force...
- Other possibilities, of course!
 - Technology may affect fertility and mortality
 - Evolution may favor groups with high fertility
 - Can AI produce ideas, so people are not necessary?