Optimal Population Size

Evidence from a Malthusian Semi-Endogenous Growth Model

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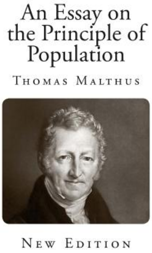

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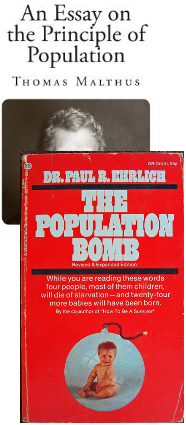

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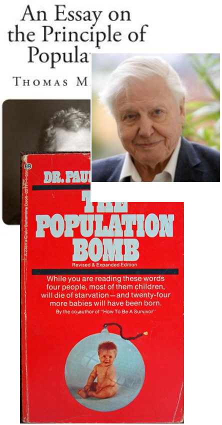

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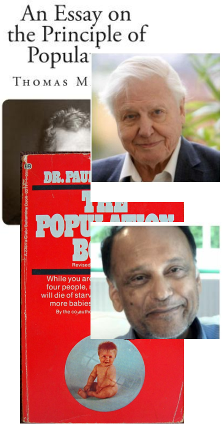

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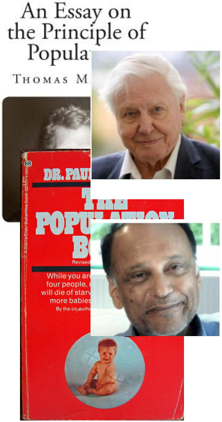

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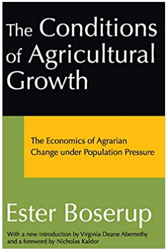

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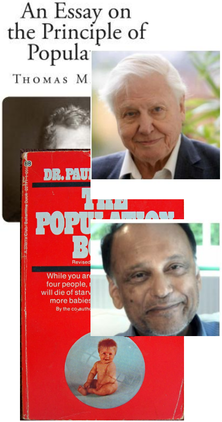

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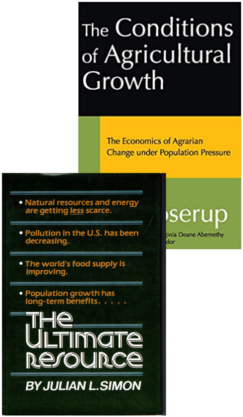

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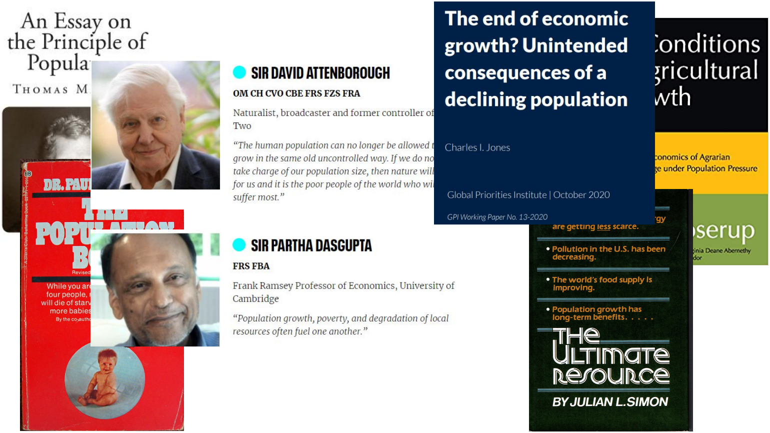

People create ideas, which can be used by everyone

Because the “people are good” logic is less well-known, consider:

1. Larger populations create more physical and non-physical goods
   - “Food” and “Ideas”
2. While the additional food needs to be divided among more mouths, the **additional ideas are not divided** in this way
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So, other things equal, larger populations have more/better knowledge, **which benefits everyone**

- In a counterfactual with fewer people, perhaps Alexander Fleming is not born and many people miss out on antibiotics

Paul Romer won the 2018 Nobel (roughly) for formalizing this idea

A modern, semi-endogenous, Malthusian model

We **quantify the relative size of these forces** using standard models

- Malthusian component motivated by Dasgupta (2021)
  - A renewable resource problem gives rise to a **fixed-factor set-up**
  - Will say more about climate change later
- Innovative component from semi-endogenous growth literature
  - As in Chad Jones' work, **people generate ideas**
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Specifically ask: How does **steady-state** per capita wellbeing, $\bar{y}$, vary with stable long-run population levels, $\bar{N}$?

- This is our key departure from Unified Growth Theory (Galor and Weil, 2000)
  - Rather than describe the past, we aim to (humbly) make out-of-sample predictions
- Focus on $\bar{N}$ because N cannot grow indefinitely
  - And as in Jones (2021): $g_N \leq 0 \Rightarrow y \to \bar{y}$

Innovation externality dominates in this framework

With only minor tweaks to standard models, we generate an **analytical solution** for $\bar{y}(\bar{N})$ in a fairly general case

- From this solution, a **sufficient statistic** arises that:
  i. Governs the elasticity of y with respect to N
  ii. Depends on recently-estimated moments
    - Bloom et al. (AER, 2020)
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Plugging in these external moments:

1. Locally, $\frac{\partial \bar{y}}{\partial \bar{N}}$ is likely **positive**
   - I.e., the innovation externality dominates
2. Globally, y-maximizing $\bar{N}$ is likely **large**
   - Unbounded(!) in the most empirically plausible parameterization

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Over the domain where current models seem reasonable, optimal population is large

Roadmap

1. Key model ingredients
2. Cobb-Douglas steady state
3. Generalized CES results
   - And other future extensions and considerations
4. Climate change
   - Overview of companion paper

Model Ingredients

Environmental Constraints

Production function between labor and natural resources

$$Y = AF(N, \bar{E}) \tag{1}$$

$\bar{E}$ is constant over time and represents the **maximum sustainable withdrawal** of environmental services.

- *Looks* like a fixed land constraint (Kremer, 1993; Galor & Weil, 2000; etc.)
- This is motivated by the endogenous solution to a more realistic subproblem

$\bar{E}$ comes from renewable resource problem

Dasgupta (2021) conceptualizes the "biosphere," B, as a **renewable resource** that humans draw on

- Regenerates as a function of its size, $\dot{B} = R(B)$

$$R(B) = rB\left[1 - \frac{B}{K}\right]\left[\frac{B-T}{K}\right] \tag{2}$$

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Drawing $E^{\star}$ is a problem that is **independent of population**

- We take as given some solution to this problem

Climate change?

Non-zero emission-intensities are **transitory**: only the next generation or two will have meaningful emissions

- A child born today will have peak emitting years of 2055-2085(?), when emission intensities will be low

In related computational work (Kuruc et al., 2022) we show that **even large, instant, changes in fertility barely influence warming**

- The story would have been different for our lives

For our purposes, larger populations have lower levels of $\frac{E}{N}$

- Other things equal, y is decreasing in N

Idea Generating Function

But, people also contribute to generating knowledge

$$\frac{\dot{A}}{A} = \theta(sN)^{\lambda} A^{-\beta} - \delta_A \tag{3}$$

$\theta =$ some scaling from research inputs to knowledge
$s =$ the share of the population contributing to knowledge
$\lambda =$ intra-period congestion effects
$\beta =$ degree to which ideas get harder to find (Bloom et al., 2020)
$\delta_A =$ depreciation of knowledge stock

- Non-standard, but natural
  - Support for this in micro data (Hall et al, 2009)
  - At societal level, need librarians and Wikipedia and JEL articles to organize and upkeep knowledge

Knowledge Steady-State

$$\frac{\dot{A}}{A} = \theta(s\bar{N})^{\lambda}A^{-\beta} - \delta_A$$

Given some stable population, $\bar{N}$, set LHS = 0 for steady-state

$$\bar{A} = \left(\frac{\Theta\bar{N}^{\lambda}}{\delta_A}\right)^{\frac{1}{\beta}} \tag{4}$$

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Knowing population we know $A \rightarrow \bar{A}$

- More people can learn more before the stock of A is too large

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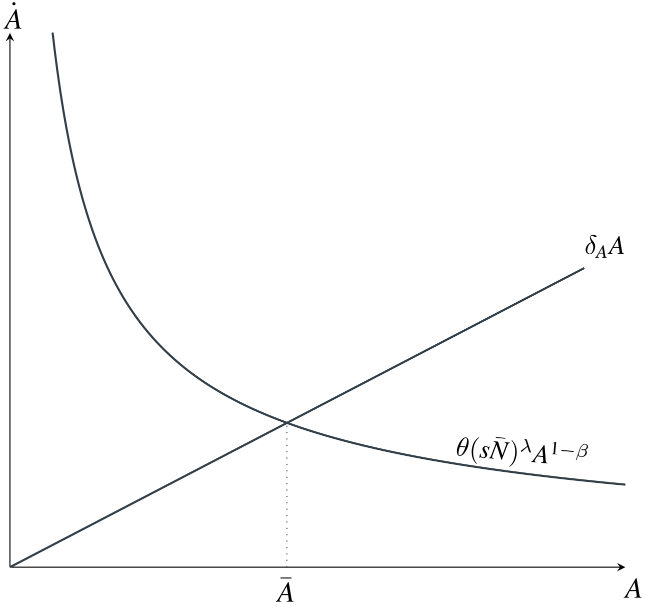

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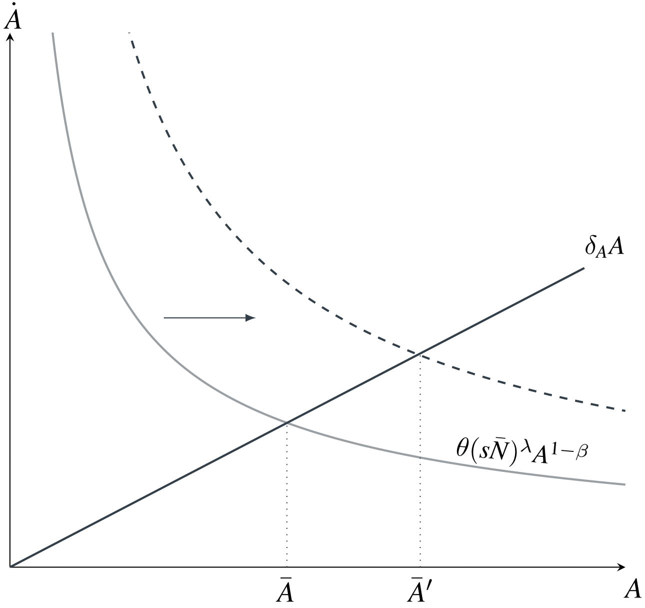

Steady State: Well-Being vs Population

Cobb-Douglas Case

$$\bar{Y} = \bar{A}((1-s)\bar{N})^{\alpha}\bar{E}^{1-\alpha} \quad \Rightarrow$$

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Sub in for $\bar{A}$

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If $\frac{\lambda}{\beta} > (1-\alpha)$, the **marginal effect of N is always positive**

- Bloom et al., estimate $\frac{\lambda}{\beta} \approx \frac{1}{3}$
- Seems very likely that $(1-\alpha) < \frac{1}{3}$

Generalized CES Case

$$\bar{Y} = \bar{A}\,\underbrace{\left[a\big((1-s)\bar{N}\big)^{\rho} + (1-a)\bar{E}^{\rho}\right]^{\frac{1}{\rho}}}_{F(N,E)}$$

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Take log derivatives for elasticity of $\bar{y}$ w.r.t $\bar{N}$

$$\begin{aligned}
\frac{\partial ln(\bar{y})}{\partial ln(\bar{N})} &= \frac{\partial ln(\bar{A})}{\partial ln(\bar{N})} + \frac{\partial ln(f)}{\partial ln(\bar{N})} \\
&= \underbrace{\frac{\lambda}{\beta}}_{\approx\frac{1}{3}} - \underbrace{\frac{(1-a)\bar{E}^{\rho}}{a\Big((1-s)\bar{N}\Big)^{\rho} + (1-a)\bar{E}^{\rho}}}_{\textbf{income share}\text{ of }\bar{E}}
\end{aligned}$$

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Monge-Naranjo et al. (2019) contributes an estimate of the income share of natural resources, ϕ_E

- *Natural Resources and the Marginal Product of Capital*

At global level $\phi_E \approx$10-15%; in developed countries 5-10%

- Even if *all* profits were E-rents in disguise, $\phi_E < \frac{1}{3}$

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Local to current population levels, **the innovation externality likely dominates the Malthusian externality**

Globally, optimal population is likely large

$\bar{N}^{\star}$ occurs when $\phi_E \to \frac{\lambda}{\beta}$

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- Complements: $\rho < 0$ implies ϕ_E grows with $\bar{N}$
  - **Local max exists iff non-fixed factors are complementary**

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Literature (e.g, Weil and Wilde, 2009) thinks that **fixed factors are substitutable**

- Time-series: ϕ_E declines with global development
- Cross-sectionally: ϕ_E negatively correlated with development

Over the range where a CES framework is reasonable, optimal population is unbounded, accounting for natural resources being fixed factors in production

Extensions (To-Do)

1. Add capital
    - Do not expect this to matter
2. Solve for a planner's optimum and other dynamic considerations
    - Crowding is instantaneous, increased A takes time
3. Explore more general production functions
    - A non-CES function that collapses to CES could give some insight over optimum
4. Allow more degrees of adjustment (i.e., s increases over time)
    - Can read our results as conditional on rule-of-thumb allocation

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In related work, I address the climate change dimension of this question

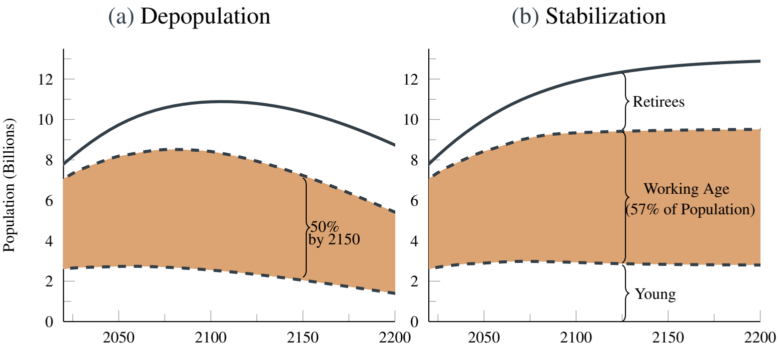
Climate effects vs. innovative effects in DICE

Joint work with Budolfson, Geruso and Spears uses DICE to study the climate costs of population versus the innovation benefits

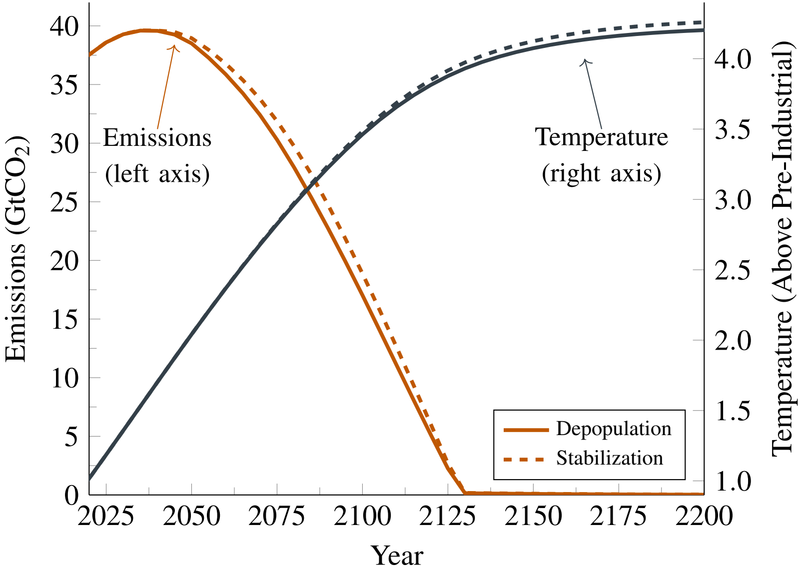
1. Use DICE's specification of $L \to Y \to E$
   - More people $\Rightarrow$ more output $\Rightarrow$ more emissions
2. Endogenize TFP as described in the same way
3. Account for "dependency ratio" effects
   - Shrinking populations have more retirees per worker

We read in a baseline case of population decline versus a scenario where fertility rates are bounded below by 2.1

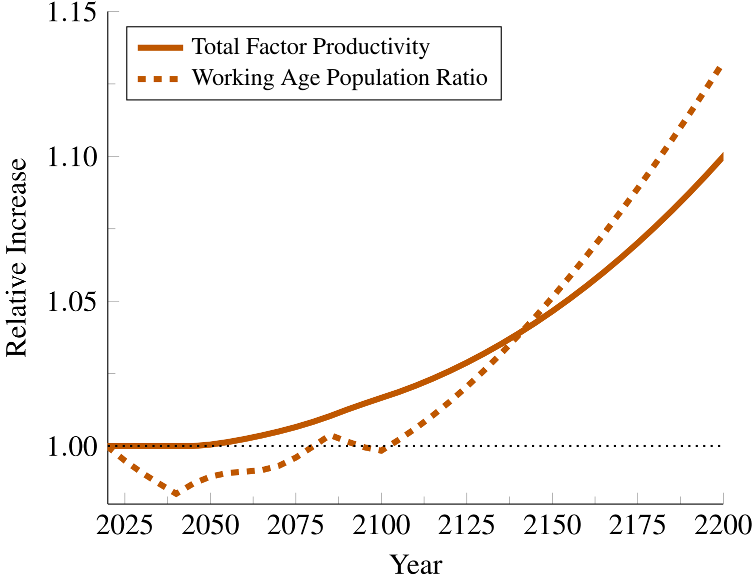
Figure 1: Population Paths



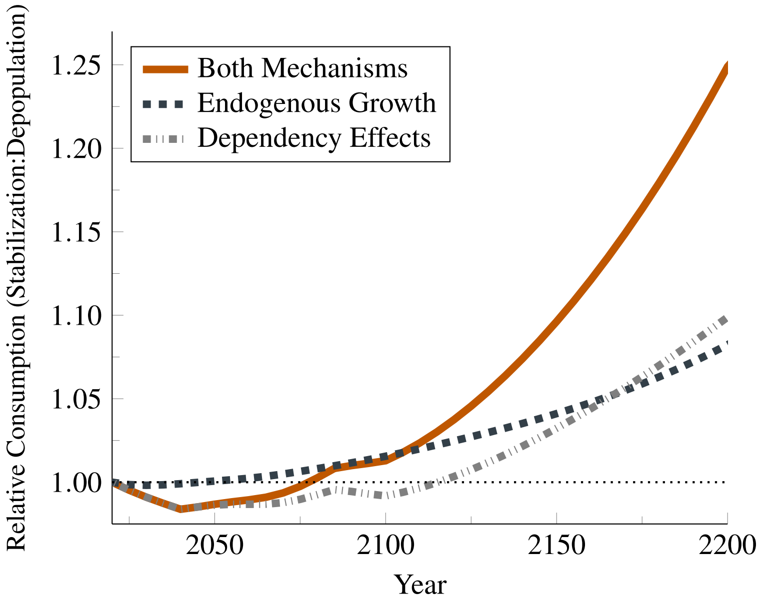
Temperature only slightly higher



TFP and working age population increase significantly



Long-run consumption net gains are large



Conclusion

I've been thinking a lot about IRS versus environmental constraints —
I have updated towards believing:

1. In a SEG framework with fixed factor:
    i. y is locally increasing in N
    ii. $N^{\star}$ is likely much larger than current global populations

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1. In a SEG framework with fixed factor:
   i. y is locally increasing in N
   ii. $N^{\star}$ is likely much larger than current global populations
2. Climate effects will not meaningfully change this story
   - Warming is very weakly increased by realistic fertility changes
     - Peak emitting years of future people will have low emissions-itensities relative to existing GHG stock
   - Elasticity of y wrt to A much higher than wrt climate damages
     - A 1% increase in A increases y by 1%
     - A 1% increase in climate damages decreases y by $\approx .1\%$