Marginal Benefits of Population

Evidence from a Malthusian Semi-Endogenous Growth Model

Maya Eden

Brandeis University
CEPR
GPI

Kevin Kuruc

University of Oklahoma
PWI, UT Austin
GPI

The University of Texas at Austin
Population Wellbeing Initiative

Is the planet overpopulated?

Would our lives be slightly better if the population was slightly larger?

- *What population size maximizes per capita wellbeing?*

Is the planet overpopulated?

Would our lives be slightly better if the population was slightly larger?

- *What population size maximizes per capita wellbeing?*

This is an old debate, spanning academic and non-academic fields

Is the planet overpopulated?

Would our lives be slightly better if the population was slightly larger?

- *What population size maximizes per capita wellbeing?*

This is an old debate, spanning academic and non-academic fields

Malthusian: Fixed natural resources $\Rightarrow \frac{\partial y}{\partial N} < 0$

- Think, environmentalists who worry we're near natural limits
  - e.g., Malthus (1798), Ehrlich (1968), Dasgupta (2021)

Is the planet overpopulated?

Would our lives be slightly better if the population was slightly larger?

- *What population size maximizes per capita wellbeing?*

This is an old debate, spanning academic and non-academic fields

Malthusian: Fixed natural resources $\Rightarrow \frac{\partial y}{\partial N} < 0$

- Think, environmentalists who worry we're near natural limits
  - e.g., Malthus (1798), Ehrlich (1968), Dasgupta (2021)

Modern Growth Theory: Increasing returns to scale $\Rightarrow \frac{\partial y}{\partial N} > 0$

- Think, optimists who believe more brains $\Rightarrow$ more progress
  - e.g., Boserup (1965), Simon (1981), Romer (1990), Jones (2021)

A modern, semi-endogenous, Malthusian model

We **quantify the relative size of these forces** by integrating leading models from respective sub-disciplines

- Malthusian component modeled as a renewable resource problem (Dasgupta, 2021)
  - People dilute limited natural resources
- Innovative component from semi-endogenous growth literature
  - **People generate ideas**

A modern, semi-endogenous, Malthusian model

We **quantify the relative size of these forces** by integrating leading models from respective sub-disciplines

- Malthusian component modeled as a renewable resource problem (Dasgupta, 2021)
  - People dilute limited natural resources
- Innovative component from semi-endogenous growth literature
  - **People generate ideas**

Specifically ask: How does **long-run** per capita income vary with stable long-run population levels?

- Focus on stable populations because:
  1. Conceptually: Populations cannot grow indefinitely
  2. Empirically: Populations are projected to level off soon

Innovation externality dominates in this framework

Using standard models, we generate an **analytical solution** for per capita income, y, as a function of populations, N

- A **sufficient statistic** arises that:
  i. Governs the relationship between y and N
  ii. Depends on recently-estimated moments

Innovation externality dominates in this framework

Using standard models, we generate an **analytical solution** for per capita income, y, as a function of populations, N

- A **sufficient statistic** arises that:
  i. Governs the relationship between y and N
  ii. Depends on recently-estimated moments

Plugging in these external moments:

1. Locally, the relationship is **positive**
   - I.e., the innovation externality dominates
2. Globally, y-maximizing $\bar{N}$ is **large**

Roadmap

1. Key model ingredients
2. Steady-state marginal results
3. Steady-state optimality results
4. Dynamic considerations

Model Ingredients

Environmental Constraints

Production function between labor and natural resources

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

$\bar{E}$ 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.)
- Motivated by the endogenous solution to a more realistic problem

Renewable resources are the relevant long-run constraint

Truly non-renewable, non-substitutable resources put a constraint on the total number of people who can ever live (Greaves, 2019)

- A smaller population can survive longer, but with the same number of total lives (which is presumably what matters)

Renewable resources are the relevant long-run constraint

Truly non-renewable, non-substitutable resources put a constraint on the total number of people who can ever live (Greaves, 2019)

- A smaller population can survive longer, but with the same number of total lives (which is presumably what matters)

Therefore, we focus on **renewable (or fixed) resources**

- Minerals, timber, fish, land, etc.
- Steady-state solutions to these problems require drawing exactly what is regenerated
  - Each year we have the same stock remaining

Renewable resources are the relevant long-run constraint

Truly non-renewable, non-substitutable resources put a constraint on the total number of people who can ever live (Greaves, 2019)

- A smaller population can survive longer, but with the same number of total lives (which is presumably what matters)

Therefore, we focus on **renewable (or fixed) resources**

- Minerals, timber, fish, land, etc.
- Steady-state solutions to these problems require drawing exactly what is regenerated
  - Each year we have the same stock remaining

Export a steady-state solution to this problem as $\bar{E}$ into $F(N, \bar{E})$

Idea Generating Function

According to endogenous growth literature, **people contribute to knowledge production**

Idea Generating Function

According to endogenous growth literature, **people contribute to knowledge production**

$$\frac{\dot{A}}{A} = \theta N^{\lambda} A^{-\beta} - \delta_A$$

$\dot{A}$ = change in TFP, A
θ = some scaling from research inputs to knowledge
λ = intra-period congestion effects
β = degree to which ideas get harder to find (Bloom et al., 2020)
δ_A = depreciation of knowledge stock

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

Non-zero depreciation produces a knowledge steady-state

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

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

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

Non-zero depreciation produces a knowledge steady-state

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

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

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

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

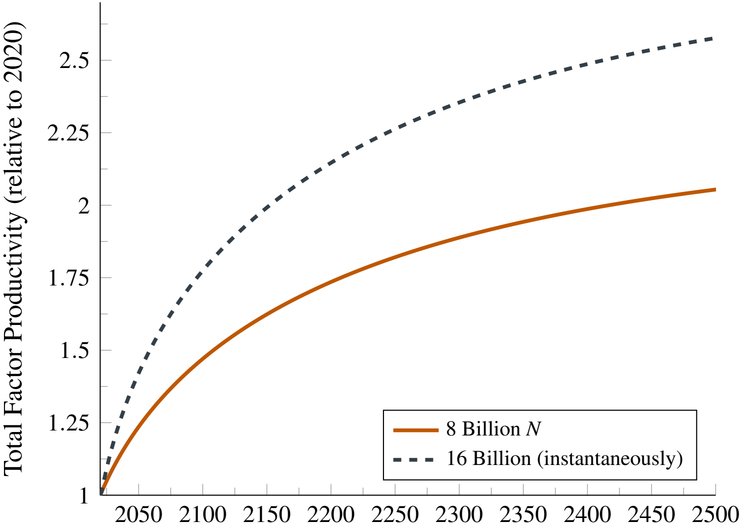
- This is an endogenous upper-bound on A

Solow Analog

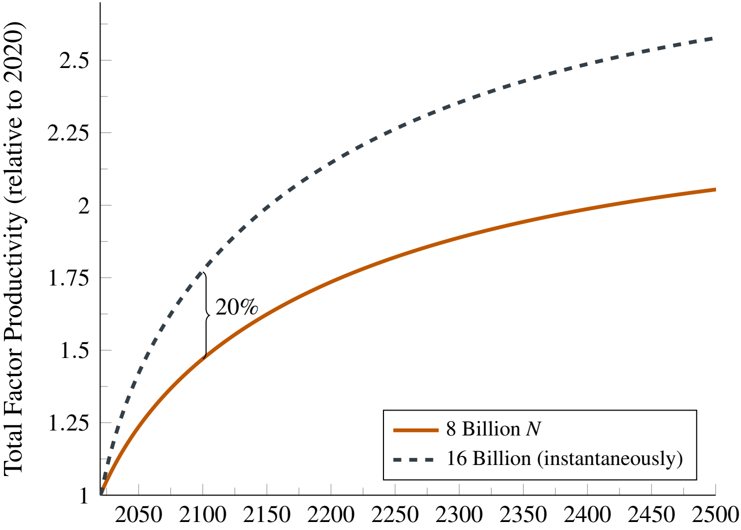
Two properties to note:

- A 2x of population leads to a $2^{\frac{\lambda}{\beta}} < 2$ scaling in $\bar{A}$
- Gains take many years to accrue

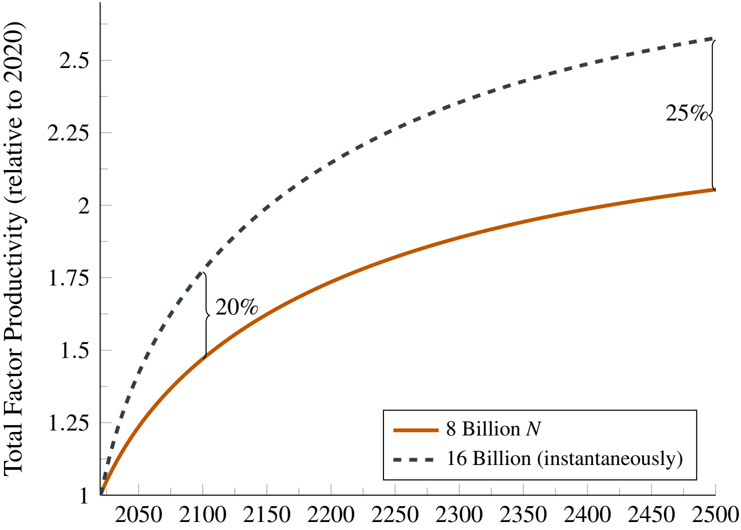
Example: Double population instantaneously



Example: Double population instantaneously



Example: Double population instantaneously



Long-run Income vs Population

Combining knowledge gains with environmental losses

Consider simple Cobb-Douglas case

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

$$\frac{\bar{Y}}{\bar{\bar{N}}} = \bar{y} = \bar{A}\left(\frac{\bar{E}}{\bar{\bar{N}}}\right)^{1-\alpha}$$

Combining knowledge gains with environmental losses

Consider simple Cobb-Douglas case

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

$$\frac{\bar{Y}}{\bar{\bar{N}}} = \bar{y} = \bar{A}\left(\frac{\bar{E}}{\bar{\bar{N}}}\right)^{1-\alpha}$$

Substitute in for $\bar{A}$ as a function of $\bar{N}$

$$\bar{y} = \left(\frac{\Theta\bar{N}^{\lambda}}{\delta_A}\right)^{\frac{1}{\beta}}\left(\frac{\bar{E}}{\bar{\bar{N}}}\right)^{1-\alpha} \Rightarrow$$

$$\boxed{\bar{y} = \Omega\bar{N}^{\frac{\lambda}{\beta}-(1-\alpha)}}$$

Combining knowledge gains with environmental losses

Consider simple Cobb-Douglas case

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

$$\frac{\bar{Y}}{\bar{N}} = \bar{y} = \bar{A}\left(\frac{\bar{E}}{\bar{N}}\right)^{1-\alpha}$$

Substitute in for $\bar{A}$ as a function of $\bar{N}$

$$\bar{y} = \left(\frac{\Theta\bar{N}^{\lambda}}{\delta_A}\right)^{\frac{1}{\beta}}\left(\frac{\bar{E}}{\bar{N}}\right)^{1-\alpha} \Rightarrow$$

$$\boxed{\bar{y} = \Omega\bar{N}^{\frac{\lambda}{\beta}-(1-\alpha)}}$$

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

- $\frac{\lambda}{\beta}$ are elasticities in knowledge generating function ($\approx \frac{1}{3}$)
  - From *Are Ideas Getting Harder to Find* (Bloom et al., 2020)
- $1-\alpha$ is the Cobb-Douglas exponent (likely $< \frac{1}{3}$)

Result generalizes to a CRS case

Assume constant returns to scale in rival inputs

$$\bar{y} = \bar{A}F\left(1, \frac{\bar{E}}{\bar{N}}\right)$$

Result generalizes to a CRS case

Assume constant returns to scale in rival inputs

$$\bar{y} = \bar{A}F\left(1, \frac{\bar{E}}{\bar{N}}\right)$$

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

$$\begin{aligned}\frac{\partial ln(\bar{y})}{\partial ln(\bar{N})} &= \frac{\partial ln(\bar{A})}{\partial ln(\bar{N})} + \frac{\partial ln(F)}{\partial ln(\bar{N})} \\ &= \underbrace{\frac{\lambda}{\beta}}_{(\frac{1}{5},\frac{1}{2})} - \underbrace{\frac{\partial \bar{E}/\partial F \times \bar{E}}{F}}_{\textbf{income share}\text{ of } \bar{E}}\end{aligned}$$

Main Result: Locally positive relationship between y, N

$$\frac{\partial ln(\bar{y})}{\partial ln(\bar{N})} = \underbrace{\frac{\lambda}{\beta}}_{(\frac{1}{5},\frac{1}{2})} - \underbrace{\frac{\partial \bar{E}/\partial F \times E}{F}}_{\textbf{income share} \text{ of } \bar{E}, \phi_E}$$

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 $\phi_E \approx 10\%$

- Even if undercounted by half, $\phi_E < \frac{\lambda}{\beta}$

Main Result: Locally positive relationship between y, N

$$\frac{\partial ln(\bar{y})}{\partial ln(\bar{N})} = \underbrace{\frac{\lambda}{\beta}}_{(\frac{1}{5},\frac{1}{2})} - \underbrace{\frac{\partial \bar{E}/\partial F \times E}{F}}_{\textbf{income share} \text{ of } \bar{E}, \phi_E}$$

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 $\phi_E \approx 10\%$

- Even if undercounted by half, $\phi_E < \frac{\lambda}{\beta}$

At (roughly) current population levels, **the innovation externality dominates the Malthusian externality**

- Long-run average income increasing in N

Need more structure to solve income-maximizing population

Consider a CES production function:

$$Y = A\left[aN^{\rho} + b\bar{E}^{\rho}\right]^{\frac{1}{\rho}}$$

For a bounded y-maximizing population to exist, it must be that the income-share of natural resources increases as populations grow

- Marginal effect goes to zero when $\phi_E \to \frac{\lambda}{\beta}$

Need more structure to solve income-maximizing population

Consider a CES production function:

$$Y = A\left[aN^{\rho} + b\bar{E}^{\rho}\right]^{\frac{1}{\rho}}$$

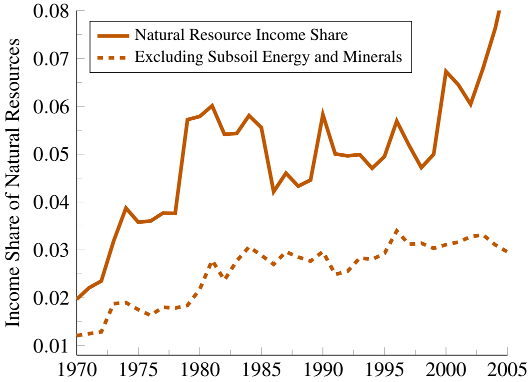
For a bounded y-maximizing population to exist, it must be that the income-share of natural resources increases as populations grow

- Marginal effect goes to zero when $\phi_E \to \frac{\lambda}{\beta}$

This will only happen if N, E are **complements**

- E becomes a smaller share of inputs, but a larger share of income

Income share of natural resources increasing over time



Simple calibration predicts that $\phi_E \to \frac{1}{3}$ when $N \approx 65$ Billion

- Point is not to be quantitative, but to show the model implies we're **far from optimal**

Dynamic trade-offs exist between short- and long-run welfare

Increasing N immediately decreases $\frac{E}{N}$, but increases A over time

- And even this abstracts from direct costs of child-raising

Dynamic trade-offs exist between short- and long-run welfare

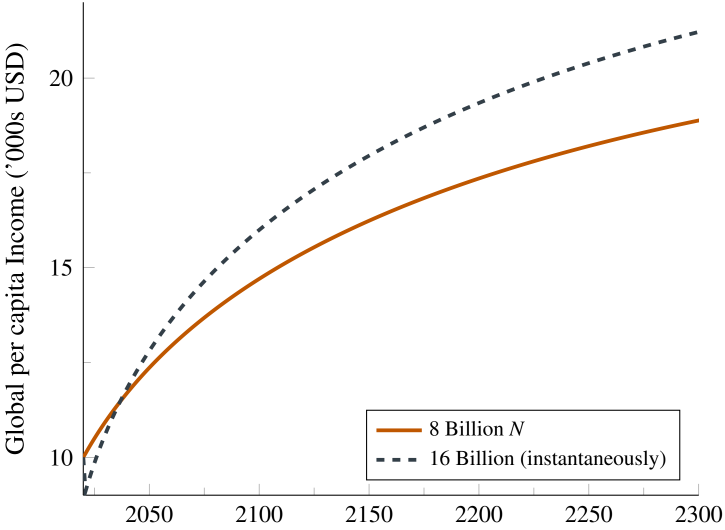
Increasing N immediately decreases $\frac{E}{N}$, but increases A over time

- And even this abstracts from direct costs of child-raising

An impatient society – even after reading this paper! – may forgoe long-run flourishing

- First pass calibration suggests this concern may not be quantitatively relevant

Gains from increasing *N* occur in our lifetimes



Discussion

Off-the-shelf models of environmental constraints and innovation (informed by high-quality empirics) implies that N increases y

Discussion

Off-the-shelf models of environmental constraints and innovation (informed by high-quality empirics) implies that N increases y

- Remains important transition dynamics to explore
  - Perhaps getting to a larger population is very costly
- Other possible ways E could be modelled (i.e., climate change)
  - Mike will say more on this next!

Thanks!

Knowledge depreciation matters for long-run welfare

Cowen (2019) argues its critical whether Solow or Romer is closer to the truth for understanding the effects of changes in economic growth

- What if Romer is right locally, but we approach something like Solow in the limit?

Knowledge depreciation matters for long-run welfare

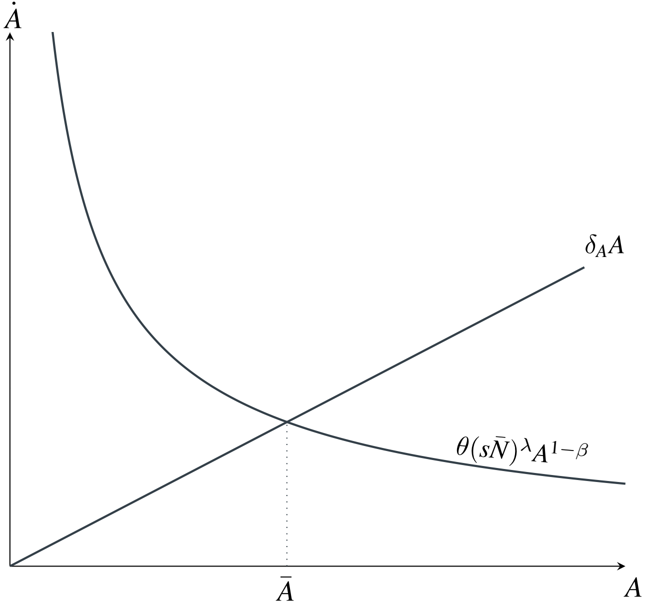
Cowen (2019) argues its critical whether Solow or Romer is closer to the truth for understanding the effects of changes in economic growth

- What if Romer is right locally, but we approach something like Solow in the limit?

Including depreciation of (endogenously produced) knowledge generates this

- Jones (2020): end of economic growth under depopulation (assumes $\delta_A = 0$)
- Us: end of economic growth under non-exponentially growing populations ($\delta_A > 0$)
  - Even if we stabilize, or boom-bust around some long-run N, eventual stagnation

Undergraduate Solow Analog



Undergraduate Solow Analog: Increase N Back