Population Growth, Ideas and the Speed of History*

Kevin Kuruc†

June 3, 2024

Abstract

Leading models imply a positive relationship between population growth and per capita economic growth—a larger labor force produces more non-rival ideas, which propel per capita productivity improvements. This paper demonstrates that this channel does *not* imply that faster population growth leaves individuals better off. The reason is straightforward: Faster population growth increases the arrival rate of both people and ideas, potentially leaving each life *ex-ante* unchanged. In ideas-based growth models, the population size governs the *speed of history*; the same events occur, they just occur earlier if the per-period population is larger. This reframing leads to two related insights. First, the distinction between processes that evolve per unit of time vs. per human life are crucial for assessing the effects of population growth. Second, for processes that evolve per human life to influence per capita outcomes, there must be a change in the number of people that *ever* live, not just the number who live in a given period. This makes assumptions about human extinction particularly important, despite the relatively limited attention (if any) typically paid to how models end.

Keywords: Population growth, economic growth, scale effects, aggregate welfare.
JEL Codes: J11; I31; O41.

---

*I would like to thank Gustav Alexandrie, Maya Eden, Mike Geruso, John Firth, Loren Fryxell, Tom Houlden, Antony Millner, Luis Mota, Toby Ord, Dean Spears, Christian Tarsney, Phil Trammell, Dietrich Vollrath, David Weil, Anson Zhou, and participants at Oxford University's Global Priorities Workshops for comments that have greatly improved the paper. All remaining errors are my own.

†Population Wellbeing Initiative, University of Texas at Austin; Global Priorities Institute, University of Oxford. Contact: kevinkuruc@utexas.edu.

1 Introduction

The human population is set to enter an unprecedented phase of decline (Basten et al., 2013; United Nations, 2022; Spears et al., 2024). From the vantage of leading theories of economic growth, this is troubling. The ideas and knowledge that propel human progress are created by people. Larger populations, other things equal, create more of this non-rival knowledge, which increases per capita living standards. Jones (2022) formalizes that an unintended consequence of declining populations may be the end of economic growth, full stop. This finding and others like it have led many to the conclusion that a benefit of avoiding population decline will be increased living standards.

Despite it seeming straightforward that everyone stands to gain from increases in the additional non-rival ideas that a larger population could produce, this paper demonstrates that this is false. The reason it fails is straightforward: population growth increases the arrival rate of *both* people and ideas, plausibly leaving each life (*ex-ante*) unaffected.[1] Put differently, scale-driven innovation explicitly cannot hold other things equal. The distribution of population across time changes alongside the increased rate of innovation; under standard parametric assumptions this effect offsets (or more than offsets) the purported benefits. Instead, I argue that we should view ideas-based growth models as demonstrating that population size governs the *speed of history*. The same events occur, a larger population just brings them forward in time. Whether and how this affects per capita living standards will depend on interactions with exogenous processes that are not accelerated alongside the arrival of people and ideas.

I begin by drawing out the core mechanism in the simplest possible setting. There are two levels of aggregate technology—say, 'pre-industrial' and 'industrial'—and two possible (constant) per-period population sizes. The key assumption is that the jump in aggregate technology happens after a sufficient number of cumulative people-years have been lived. Cumulative people-years could be taken to proxy total human effort spent learning-by-doing or the random arrival of intellectual breakthroughs that a given individual could make. This is not a novel assumption: it is the implication of standard parameterizations of standard long-run growth models. While mathematically equivalent, this reframing from 'per period population size drives per period innovation' to 'cumulative population size determines cumulative innovation' makes immediately clear why this channel of scale-driven growth does not improve any individual life: A fixed number of people will live in the low-tech state before the required cumulative people-years are reached, regardless of per-period population sizes. Similarly, every life beyond that threshold of cumulative people

[1] For brevity, I will not state this *ex-ante* qualifier throughout the paper. It applies unless stated otherwise.

years occurs in the high technology state. Increasing the size of the population succeeds in bringing forward the date at which certain ideas are discovered, but it does so by bringing forward every individual life. Therefore, the technology available to each individual is invariant to population sizes, even when the macroeconomy exhibits this well-known channel of increasing returns to scale.

After developing the key intuition in a simple model, I formalize the main claim of the paper using a standard semi-endogeous growth framework. This framework has continuous TFP improvements and allows for an arbitrary path of population size over time. I demonstrate that the mapping between individual experiences and the TFP available at the time of each experience is fully determined by where in the order of human experiences it is, not on the size of the population in any period. Therefore, just as in the simple model, for a fixed number of lives, larger per-period population sizes only affect how fast events unfold in these models.

This finding alone does not imply that increasing the population size has no effects, or even that scale-driven growth has no effects. Interpreting population size as governing the speed of human history makes clear how this could be. To take a particularly stark example, consider a civilization that faces some exogenous probability of extinction each period. Speeding up human history would of course have effects under this assumption: more lives and discoveries would occur in our (ex-post) fixed number of periods. On the other hand, suppose civilization faces endogenous threats arising from something like a risky technology being developed. In this case, extinction is also brought forward by increasing the speed of human history, undoing the effects of a larger population in early periods.

The extinction assumption is particularly useful to think through because it changes the number of *timeless* existences—i.e., the number of lives ever lived, irrespective of when they live. It turns out, for factors that evolve per human-life, this is precisely what needs to change for that factor to have a per capita effect. In the case of idea-based growth, each individual life is the same *conditional on existing*, a qualifier I omitted in the earlier description of the main result. But it turns out to be crucial: the marginal person has the life with the highest level of TFP available to them. The implication of ideas-based growth models is that timeless per capita wellbeing increases in the size of the timeless population (i.e., it implies increasing returns to scale over the whole of human history), so a stance on what determines the number of people to ever live must be taken. The intuition of this is straightforward from the vantage of the ‘speeding up history’ framing: To assess the effects of speeding up the conveyor belt of history, we must know what’s at the end.

The general lesson outside of ideas-based growth models is that it is necessary to formalize whether a particular factor advances per unit of time, or per human life when assessing the nature of scale effects. To consider other well-known forces that could drive aggregate scale effects, suppose ecosystem services arrive and regenerate at a rate independent of economic activity. A larger population, by increasing the speed of human history, decreases the *relative* speed of ecosystem regeneration. Per human life, there is less regeneration which is straightforwardly bad for individuals. On the other hand, suppose there are exogenous fixed costs that need to be paid each temporal period, such as someone learning how to fill a particular specialized niche in the economy. Then, speeding up the arrival rate of people is beneficial: the fixed costs are smaller per human life, since more lives are lived per temporal period. The main point is not to take a stance on which of these other factors dominate, but to make clear that whether certain forces are exogenous or endogenous to the arrival of people and ideas will be critical for understanding the effects of population size.

This paper contributes to literatures at the intersection of scale economics and long-run economic growth. Since Romer (1986, 1990) increasing returns to scale has been at the center of long-run studies of economic growth. Jones (1995) builds on this insight to highlight the importance of population growth (see also Jones, 2003, 2005, 2022). To summarize the findings from this body of work: exponential growth in aggregate research inputs can be maintained only if the population grows exponentially, so the rate of population growth is the *only* variable that determines long-run economic growth. Correspondingly, the most recent paper in this series demonstrates that negative population growth leads to the end of economic growth (Jones, 2022).

This counter-intuitive idea—that long-run population growth is the driver of long-run economic growth—sparked a series of papers attempting to eliminate these scale effects (Dinopoulos and Thompson, 1998; Segerstrom, 1998; Young, 1998). Jones (1999) shows these attempts fail to eliminate the scale effects in levels; a larger population is still richer per capita each period, even if faster population growth no longer leads to faster economic growth. The link between the non-rivalry of ideas and increasing returns to scale has been seen as a deep feature of long-run growth ever since.

The contribution of this paper is to demonstrate that these scale effects may be something of an illusion, or at least more contingent than the consensus currently holds. If we focus on the well-being of people, rather than time periods, the results in this paper show that per-period scale does not, on its own, leave anyone better off. If ideas-based growth is to improve per capita outcomes, it must come through a channel of more people *ever* living. Indeed, Section 3 demonstrates a simple way to fully eliminate per-period scale effects, even in a setting where ideas are non-rival and their production is increased by the size of the population which have been long thought to necessarily imply them. In scenarios where scale effects persist because larger per period populations increase the number of people that ever live, we nonetheless have a very different reading of what is happening: the way in which per capita outcomes are improved is by allowing for the existence of additional people who live above average lives.

By asking about the implications for long-run welfare of these models—that is, the quantity and quality of human lives ever lived—this paper also intersects with a literature in applied welfare economics. Most relevant is Klenow et al. (2023), which accounts for social welfare gains coming from population growth versus income growth. They find that increases in the quantity of lives may matter more than the increase in living standards over this period. Other papers in the literature of applied population ethics have similarly found the quantity of lives to be an important determinant of social welfare (see e.g., Lawson and Spears, 2023).

Similarly, there is a recent literature interested in endogenous risks to humanity's survival that directly deals with the question of how many people will ever live. Greaves (2019) studies the case of climate change, where each human life has some non-zero carbon footprint in the long run. She shows that this implies that a fixed number of people can ever live: either the planet is warmed beyond a level that we could survive, or we run out of whatever the necessary dirty input is. The present study works with a premise that is more relevant for economists (and more realistic), but generates analogous takeaways using a similar style of reasoning. Jones (2016, 2024) studies problems where the risk of extinction endogenously evolves with technology, similar to what is implied here, but instead studies the growth-safety trade-off. Aschenbrenner and Trammell (2024) likewise study a growth-safety trade-off faced by a planner who can invest in safety technology as well as consumption enhancing technology, asking whether technological growth is in general beneficial for increasing the number of people who ever live. Finally, Ord (2024) develops a very general framework for assessing the long-run welfare implications of changes to the joint trajectory of life-quality and survival-probability of humanity over time. Seen from Ord (2024)'s framework, I show that population size is a method of speeding up events, coming to an analogous conclusion that the effect of accelerating progress importantly depends on assumptions about extinction.

2 Ideas-based growth models do not imply a positive relationship between population size and individual living standards

This section first presents the simplest model that illustrates the main point of the paper and then formalizes this finding in a canonical version of a general semi-endogenous growth framework. The key assumption in the simple model is that the level of technology in a given period is a function of cumulative people-years lived prior to that year, which I later show is the implication of standard endogenous growth frameworks. I then show that this assumption implies that each individual's income is invariant to historical flow population sizes, even though larger flow population sizes increase the rate of productivity growth. After developing the intuition in the simple model, I formalize this proposition.

2.1 Simple two-technology, endogenous growth model: Population size governs the *speed of history*

This section will work with the most transparent version of a model that leverages the key feature of ideas-based growth theories: the level of innovation in a period depends on cumulative economic activity prior to that period. Time, t, and the per-period population size, $N(t)$, are continuous. There are two possible technology levels, $A = \{Lo, Hi\}$, representing periods with low or high per capita living standards. A increases from $Lo \rightarrow Hi$ after some fixed number of people-periods, M, have been lived. For ease of exposition I will assume that each individual lifetime is only one period, so that M is a measure of lifetimes that need to be lived before humanity's accumulated knowledge is enough to transition from $Lo \rightarrow Hi$.

Figure 1: Larger populations speed up economic growth

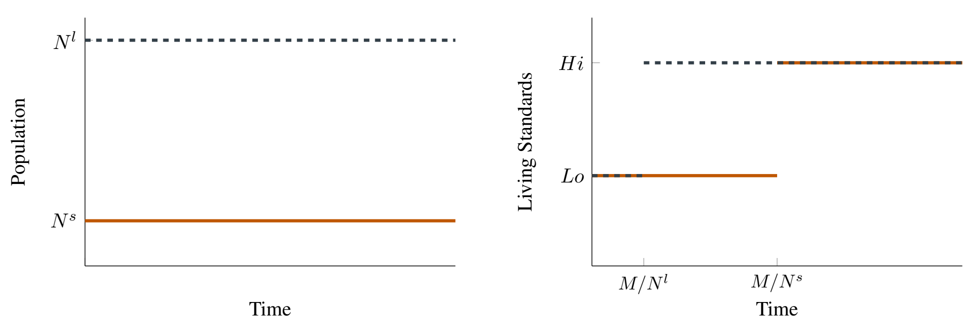
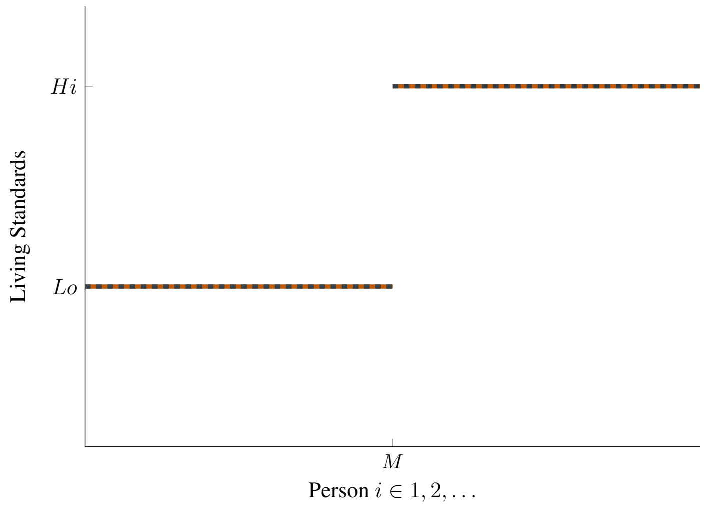


Figure 1 depicts this simple economic environment for two hypothetical population sizes. For

Figure 2: No individual has a better life because of the faster growth



simplicity I will depict these graphs for some fixed $N^s(t) = N^s < N^l = N^l(t)$. In the history with a large population, the jump from $Lo \rightarrow Hi$ happens earlier. Equivalently, economic growth is faster in the larger population history.

Now, imagine that we can identify each person i in history by the order of their birth. In other words, we are counting the number of people who have ever lived as they are born. So far there have been about 100 billion people who have ever been born, so each of us alive now would be i's in the 100 billions. Our grandparents were the lower is; our grandchildren will be the higher is. Consider the living standard of any i in the high and low population histories of Figure 1. A larger population history brings forward the is just as fast as it brings forward the jump to Hi. What is different is merely the date at which an individual exists. Figure 2 depicts this outcome by graphing living standards for each i, rather than for each period t. From this vantage, the two histories are exactly identical, aside from the speed at which history has progressed. The next subsection formalizes this result, but Figure 2 captures the key intuition that is the main contribution of this paper.

2.2 Formally: The TFP available to each individual-moment depends only on where it lies in the order of human-experiences

Equation 1 is a production function of productivity improvements (i.e., *ideas*) that is standard in the endogenous growth literature that I am engaging with (e.g., Jones, 2022).

$$\frac{\dot{A}(t)}{A(t)} = \alpha(t)(s(t)N(t))^{\lambda}A(t)^{-\beta} \tag{1}$$

Time, t, is continuous; $\dot{A}$ is the instantaneous change in productivity, A. This depends on three factors. First, the number of individuals engaged in research. In (1) this is decomposed as the share of the population in research, s, multiplied by the population size, N. Second, the productivity of these researchers, α. Third, the accumulated knowledge stock, $A(t)$, which allows for non-linearity in idea production. This could speed up productivity improvements ($\beta < 1$) if we use past inventions (e.g., the computer) to help generate new inventions, or it could represent a slowing down ($\beta > 1$) if earlier discoveries are systematically easier to make. In practice, $\beta > 1$ matches the historical data better, both in aggregate and at the industry level (Bloom et al., 2020).

Notice that the number of researchers is raised to some power λ that determines whether there are diminishing returns to researchers within a period. There is considerable uncertainty about what value λ should take. One reason to believe that $\lambda < 1$ is *duplication*; people alive at the same time might solve the same problems, resulting in wasted effort. On the other hand, *collaboration* might be a reason that $\lambda > 1$; the ability to communicate with other researchers might result in faster progress than a counterfactual where those same researchers have non-overlapping lives.[2]

The intuition behind Equation 2 is simple: if ideas are produced by people, then a larger population ought to produce more of them. Productivity increases should be faster, other things equal, in periods with larger populations. Romer (1990) recognized that non-rival ideas would give rise to increasing returns to scale. Work since then has confirmed just how difficult it is to neutralize this scale effect in idea-based growth models (Jones, 1999).

For expositional simplicity, let $\lambda = 1$ and $s(t), \alpha(t)$ be some constants $\bar{s}, \bar{\alpha}$. The assumption of constant α, s, is employed because the objective is to isolate the effects that population size changes have. Of course it is true that increasing α or s would also increase economic growth rates, but that is not the focus of this paper. The assumption of $\lambda = 1$ is more substantive. It

[2] In reality, this relationship likely has an 'S'-shape, where collaboration benefits dominate at small populations, but duplication issues dominate for large populations. It is unclear which dominates for current population sizes.

imposes a constant marginal effect of population within a period (i.e., if the world population were twice as large, exactly twice as much progress on productivity improvements would occur). In Section 3.3 I will explore how the implications of the model change for other values of λ, showing that the overall takeaways are not importantly changed.

With these assumptions, we can rewrite (1) as follows, where $\theta = \bar{\alpha}\bar{s}$.

$$\frac{\dot{A}(t)}{A(t)} = \theta N(t) A(t)^{-\beta} \tag{2}$$

Integrating both sides with respect to t delivers the following expression for the level of A.

$$A(t) = \left(\beta\theta \int_0^t N(\tau)d\tau + A_0^\beta\right)^{\frac{1}{\beta}} \tag{3}$$

Equation 3 captures the core idea leveraged in the simple model of the prior subsection. It indicates that the level of $A(t)$ is determined by $\int_0^t N(\tau)d\tau$. That is, cumulative innovation by period t is pinned down by cumulative people-years lived by period t. This is not how this class of models is typically described, but the intuition is straightforward. If innovations and ideas contribute to a non-depreciating, non-rival stock of knowledge that is built over time by people, the stock of available ideas will be larger after more people have ever lived. Notice that this does not need to be a linear relationship. In the case where $\beta > 1$, a person-year lived when the knowledge stock is large will generate a smaller increase in A.

Substantively, what Equation 3 does is eliminate t as an independent variable. It is cumulative human effort, not time, that drives innovation. Time is correlated with innovation *because* it is correlated with cumulative human effort. So, we can eliminate time as an independent variable without losing anything of conceptual importance.

It is necessary to be more specific about what i is in this continuous time setting. In the simple model of Section 2.1 I called i a person, but in continuous time it is more accurate to think of it as a person-experience—it is an instantaneous experience had by some individual. Formally, let $i(t)$ represent the count of these experiences that have happened by moment t, continuing to be measured in units of people-years.

$$i(t) = \int_0^t N(\tau)d\tau \tag{4}$$

For a population of 10 people, after precisely 2 years this population will be at $i = 20$ person-years lived. Additionally, let the wellbeing each instantaneous experience i be proportional to

TFP available at the time that experience is happening. This is equivalent to the standard case of defining utility as a simple function of consumption or income. I will define TFP accessible for person-year i as $A(i)$.

$$y(i) = C \times A(i) \tag{5}$$

Recall that Equation 3 implied that $A(t)$ is a function of people-years, which are now denoted i. Therefore, the expression for $A(t)$ can be simply rewritten as a function of i.

$$A(i) = \left(\beta\theta i + A_0^{\beta}\right)^{\frac{1}{\beta}} = \frac{y(i)}{C} \tag{6}$$

This result makes clear that the experience of person-year i is pre-determined by it's order in history. The arrival of this experience can be accelerated by increasing the arrival rate of people-years, but the wellbeing of this experience cannot be improved via scale-based growth. On its own then, it appears scale-based growth has no effects on people's lives in expectation, even if it has the measured effect of increasing rates of economic growth. The next section shows that this further claim—that the population size is exactly neutral in these models—depends on how they are "closed", i.e., how the model is assumed to end.

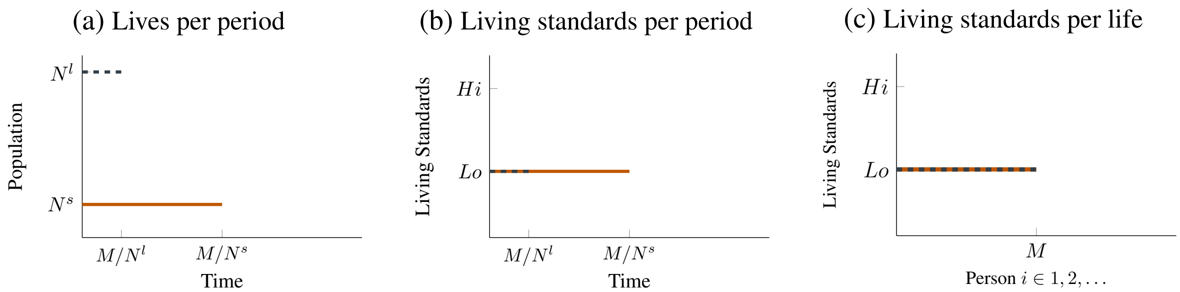
3 The overall effects of scale-based growth depend on how the model ends

Section 2 demonstrates that the quality of each experience, i, is unchanged via scale-based growth. What was not stated was the implicit assumption that i *happens* regardless of the per period population size. This section uses two opposing views on the extinction risks that humanity faces to show that scale-based growth can improve the average experience if larger per period populations increase the number of lives that ever happen.

3.1 Endogenous Extinction

Suppose, in line with the views of leading scholars of extinction threats, that nearly all of the risk that civilization faces is *endogenous* (Rees, 2003; Ord, 2020; MacAskill, 2022). That is, human extinction is likely to be caused by some technology being used by some human beings. Within economics, consider Jones (2016)'s "Russian Roulette" model of growth; each new idea or technology has some probability of ending civilization.[3] Similarly, each person has some probability of doing something intentional—releasing a bioengineered pandemic—or unintentional—being in contact with a novel pathogen from nature—that could kill all of humanity.

Figure 3: With endogenous extinction, total lives are invariant to per-period population sizes



An assumption like this breaks the first-order link between per period populations and the number of total people who ever live. This is easiest to see when we leverage the intuition that the size of the population governs the speed of human history. If the probability of extinction advances per human life, either directly or indirectly, then its arrival will be brought forward just as existences and innovations are. Take the model Section 2.1 and layer Jones' "Russian Roulette" idea on it: once we reach $A = Hi$, humanity ends quickly thereafter because $A = Hi$ turned out to contain extremely dangerous ideas and technologies. Then, M people will live, regardless of how large or small populations are per-period. We are either spread out over many years, or have a higher density over fewer, but the same number of lives happen.

Figure 3 graphs this case. Both populations get to M people-lives and then go extinct. The picture in panel (c) is so simple precisely because time is not graphed. These histories play out on different timelines, but under the assumption that every individual—conditional on A—advances progress by the same ex-ante amount, we will reach the (ex-post) dangerous technology after the same number of existences.

Before moving on to the case of exogenous extinction, it is interesting to note that this result harkens back to an old literature attempting to eliminate scale effects in growth models (see e.g., Dinopoulos and Thompson, 1998; Segerstrom, 1998; Young, 1998). Jones (1999) demonstrates that these efforts were unsuccessful—though these models eliminate the scale effect in growth, all retain at least a scale effect in the level of per capita incomes. Here we find a model that in some sense eliminates scale effects: larger per period populations do not raise per capita incomes (when

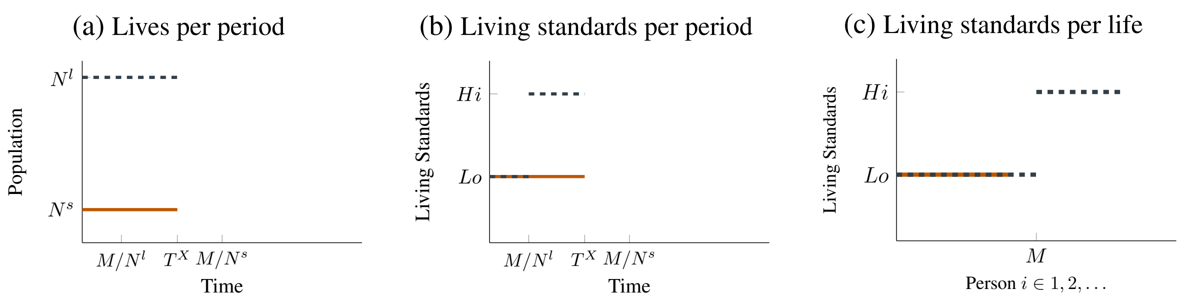
[3] See also the specific case of turning on a potentially dangerous artificial intelligence (Jones, 2024).

measured over time) even though ideas are non-rival. The intuition is that an extinction event is *also non-rival and its probability of occurring also increases in population size.* Endogenizing extinction in this way endogenizes an offsetting mechanism that undoes the benefits that accrue earlier in time.

3.2 Exogenous Extinction

An arguably simpler case is exogenous extinction: each period, there is some probability that a non-human induced catastrophe wipes out civilization (e.g., an asteroid). For simplicity, I will treat this as ex-post deterministic, even though individuals living within the model would treat it as ex-ante stochastic. Call the year we go extinct via natural causes T^X. The result of this will again be obvious using the *speeding up history* framing: larger per period populations increase the arrival rate of ideas and people, and thus compresses more events into same amount of time that history exists. In other words, more of the pre-determined history happens when populations are larger.

Figure 4: With exogenous extinction, larger populations get through more of human history



To see this graphically, consider Figure 4. Here I've again assumed the two population sizes under consideration are some fixed N^s, N^l. Furthermore, imagine that T^X is such that $N^s \times T^X < M < N^l \times T^X$; the smaller population does not generate enough cumulative people years prior to extinction to progress to $A = Hi$. The large population does.

These curves overlap for all $\int N(\tau)d\tau \leq N^s \times T^X$. At this point, the small population has gone extinct. The large population proceeds on the same path until $N^l \times T^X$. Humanity progresses through more of its potential history before the period of extinction.

There are two related lessons to draw from these contrasting outcomes. The first is that if scale-based growth interacts with exogenous phenomenon, it can have aggregate effects. In this case, what matters is the relative arrival rate of extinction, lives and ideas. The arrival of lives and ideas is sped up by population size without speeding up the arrival of extinction, causing this scenario to proceed through more lives and ideas. Similarly, it could be the case that this event is only an extinction event if technology levels are low; then speeding up the arrival of ideas leaves humanity more prepared for exogenous temporal events. I will return to this lesson in Section 4.

The second lesson is that the increase in per capita wellbeing from scale-based growth here comes via the extensive margin. That is, no life is made better off if it is lived in both population scenarios (see the overlap in Figure 4), but the marginal existences are high quality, pulling up average wellbeing. The main proposition in Equation 6 shows that this must be the case: each i has an identical life, but expanding the set of $i \in [0, I]$ results in a higher average, because the additional lives are necessarily lived after more human effort has gone towards idea-creation. So the increasing returns to scale persist from a *timeless* perspective. A larger timeless population produces better per capita outcomes. But, the increase in per capita variables comes from adding more good lives—a distinct mechanism by which we would typically think per capita outcomes could be improved.[4]

Before moving on, I should note that these are certainly not the only ways one could conceptualize extinction threats. If, as many ecologist believe, the biggest threat to long-term survival is per-period overuse of resources that would otherwise regenerate, it could be that *smaller* per period populations maximize the expected number of lives ever lived. If so, scale-based growth models would imply that per capita wellbeing is maximized by shrinking the population, because this channel operates entirely via the number of people who ever live. The point here is not take a stance on which extinction assumption is most reasonable, but to demonstrate that whether scale-based growth models indeed link per period populations to per capita outcomes necessarily depends on the extinction assumption employed.[5]

[4]This would be like saying "population growth in rich countries is good for per capita outcomes because these additional individuals have higher than average welfare." While true, it is certainly not obvious that is what is typically meant when we think about per capita wellbeing being something we aim to maximize.

[5]Jones (2022) employs a novel extinction assumption in his study of economic growth under declining populations: birth rates remain below replacement, such that the population exponentially shrinks to zero in the long-run. This explains his result about economic growth ending—eventually there are zero people on the planet, so there is no one around to create any new ideas.

3.3 Diminishing intra-period returns to population size do not change the qualitative takeaways

This section demonstrates that the assumption of within-period linearity between population size and TFP growth does not drive the qualitative takeaways, once the extinction assumptions are seen to be crucial. This simplification makes the results stated so far analytically exact, but it does not drive the first-order takeaways.

Below I reprint for convenience the standard endogenous growth equation that I began with, including the simplification that $\alpha(t), s(t)$ are fixed constants.

$$\frac{\dot{A}(t)}{A(t)} = \theta N(t)^{\lambda} A(t)^{-\beta} \Rightarrow$$
$$A(t) = \Big(\beta\theta \int_0^t N(\tau)^{\lambda} d\tau + A_0^{\beta}\Big)^{\frac{1}{\beta}}$$

The assumption that $\lambda = 1$ is the linearity assumption that I have worked with to generate the exact result that the arrival of ideas and lives occurs proportionately. Formally, it is the assumption that implies the integral is simply cumulative people-years, regardless of how they are distributed over time. However, this is a knife's edge condition where agglomeration effects exactly offset duplication concerns.[6] Here I will consider cases where $\lambda < 1$, as this is the more widely applied assumption in this literature. This implies that increases in human effort pass less than propotionately to TFP improvements. Intuitively, a larger population would speed up the arrival of people and ideas, but it speeds up the arrival of people slightly more.

In one way, this creates a very novel and unintuitive implication: idea-based growth models imply that each individual life is better in a *smaller* population world even with Romer-style (per-period) increasing returns. If $\lambda < 1$, a larger population increases the arrival of people faster than ideas, which leaves each individual life strictly worse off.

However, as highlighted in Section 3, how the model is closed turns out to be crucial in understanding the overall effects. This ends up eliminating most of what is counterintuitive here. Again, first consider endogenous extinction via "Russian Roulette" growth. A larger population speeds up the arrival rate of people, but does not speed up extinction quite as fast (since extinction is tied to TFP levels, which have not been accelerated as fast as lives). So, more people end up living when per period populations are larger. In other words, TFP in this larger population still reaches an

[6] Recall that duplication concerns are that if more people are researching in any given period, the probability of overlapping findings is higher, so it is not a one-to-one pass through from population to new non-rival knowledge.

upper-bound at whatever level of A (ex-post) introduces the technology that kills everyone, which offsets the benefits to the earlier people of smaller populations. When (i) $\lambda < 1$ and (ii) A causes extinction, then we have that larger per period populations increase timeless population sizes, but do not increase per capita well-being—a similar result to endogenous extinction with $\lambda = 1$.

If extinction is exogenous—the case of an asteroid—the qualitative results are likewise analogous to the case of $\lambda = 1$. Even when $\lambda < 1$ larger populations produce more ideas. So, a larger per period population with exogenous extinction continues to make it through more total lives, which implies they will make it through more total discoveries. Duplication concerns reduce the degree to which per capita outcomes are improved, but not whether it is true. If (i) $\lambda < 1$ and (ii) extinction is exogenous, then we have that a larger per period population increases total existences the average quality of existences, just as in the case of $\lambda = 1$.

Finally, consider a new case where extinction is entirely human-driven. This case was analogous to being technology driven when ideas and people accelerated one-for-one, but here it will have different implications and is worth separating out. If the proper model of extinction is something like 'each person has some exogenous probability of being evil enough to want to end civilization', then humanities lifespan is tied to cumulative people years directly (not indirectly through A). This is the case where λ does matter for the qualitative takeaways. If $\lambda < 1$ a larger population speeds up the arrival of people (and now extinction) *faster* than it speeds up the arrival of ideas. So, larger per period populations result in the same number of people ever living, but they achieve a lower level of average wellbeing than if that same number of people were spread out over time. The effect of spreading people out is lessening the problem of congestion or duplication without changing the number of people who ever live. This is strictly beneficial. While I consider this model of extinction the least-plausible intuitively, it demonstrates that there exist realistic assumptions by which the implications of scale-based growth are entirely overturned. Furthermore, if extinction is based on resource exploitation within a period—e.g., if too many trees are used per period, ecosystems eventually collapse—a similar result could be generated.

Of course, non-linearities could also be introduced into the process of extinction risk. I only employ these simple cases to highlight the dramatic differences in the implications of ideas-based growth models that arise when different assumptions are employed. The general takeaway is that population size, ex-ante, speeds up the arrival rate of lives, ideas and (plausibly) extinction risks. The relative increase in these different processes will be what determines whether population size has any effects via these channels.

4 Temporal variables vs. endogenous variables

This section discusses how the general framing of this paper—that the population size governs the arrival rate of people—can be applied in other contexts where scale effects have been hypothesized to be important. As in the exogenous extinction case, it will continue to be true that identifying processes that evolve independent of the size of the population will be the key to identifying cases where population sizes can make a first-order difference to per capita outcomes.

The most widely discussed scale effect is the Malthusian concern that natural resources are fixed. It is easy to verify that this is an exogenous factor that evolves on a fixed temporal scale: each period nature produces some fixed amount of ecosystem services that can be used/consumed. If the arrival rate of human lives is accelerated, without accelerating the speed of ecosystem service delivery, functionally the result is that the arrival rate of ecosystem services has been slowed down *per human life*. This will straightforwardly leave individuals worse off, as can be seen by in a very simple three-equation model below.

$$\begin{aligned} y(i,t) =& f(A(i,t), e(i,t)) \text{ with } \frac{\partial y}{\partial A}, \frac{\partial y}{\partial e} > 0 \\ A(i,t) =& \left(\beta\theta i + A_0^{\beta}\right)^{\frac{1}{\beta}} \\ e(i,t) =& E(t)/N(t) \end{aligned}$$

The first equation states that per capita income is an increasing function of TFP and natural resources accessible to individual i. The second equation is the earlier result that $A(i,t)$ only depends on i's order in history. The third equation is the constraint that per capita resource use *in a period* is the aggregate amount provided by nature in that period spread across the population alive in that period. It is straightforward to see that, since $A(i,t)$ is invariant to N, but $e(i,t)$ declines in N, that $y(i,t)$ declines in N. What is interesting in this case is that the per period losses from this channel might be trivial relative to the measured gains of increased innovation per period if we were to study how per capita income changed over time in relation to population sizes.

On the other hand, consider fixed costs—a well-known channel by which increasing returns to scale can be generated. If these are one-time fixed costs (like those of inventing a new product), I have already shown that speeding up the arrival rate of lives will not leave anyone better off. The cost of inventing the product needs to be paid once over the history of humanity, and its per capita cost is not reduced by having people show up faster. However, some fixed costs have a temporal element. Labor specialization is one such case: an individual pays the fixed cost of learning some skill that they can apply for the entirety of their working life (say, 50 years). On aggregate, therefore, each of these specialization costs needs to be paid once every 50 years to always have someone who can fill a particular niche. Increasing the arrival rate of people lowers this per capita cost, since more people live in each of these 50-year periods.

There are other factors that have been less widely explored. Take knowledge depreciation, for example. It is possible that humanity loses skills, or collectively forgets ideas, if skills and ideas go unused. If there is a temporal element to this, then again, it's best to have people arriving faster to mitigate this depreciation per human life. On the environmental side, too, we might expect a wide range of challenges to advance per unit of time. Rather than take a stance on which effects will be most important, the point here is to highlight that thinking about whether the process depends on time or on human lives will be crucial in understanding whether speeding up the arrival rate of people will change the costs/payouts per human life.

5 Discussion and Conclusion

The size of the human population is almost certain to begin shrinking later this century. According to leading theories of endogenous growth, whether humanity stabilizes at 8 billion, rather than 4 billion, for example, will influence rates of economic growth. At first glance, this appears to be reason enough to prefer stabilizing at larger population levels.

This paper shows that this is not in fact the case in standard models that generate a positive population-productivity growth relationship. These models imply that, because the arrival rate of ideas depends on the arrival rate of individual lives, a larger population leaves no one better off. Improving living standards via additional economic growth is not on its own a reason to prefer larger populations.

Whether scale-based economic growth improves per capita outcomes depends on whether larger per period populations lead to more lives to ever happen. This implies that these models need to make particular assumptions about human extinction to generate a relationship between the living standards for individuals and per period population sizes. This is a question economists have paid relatively little attention to, but appear to be crucial for understanding the implications of long-run economic growth through different channels.

References

Aschenbrenner, L. and Trammell, P. (2024), 'Existential risk and growth', *Global Priorities Institute Working Paper* . Available at: https://philiptrammell.com/static/Existential_Risk_and_Growth.pdf.

Basten, S., Lutz, W. and Scherbov, S. (2013), 'Very long range global population scenarios to 2300 and the implications of sustained low fertility', *Demographic Research* **28**, 1145–1166.

Bloom, N., Jones, C. I., Van Reenen, J. and Webb, M. (2020), 'Are ideas getting harder to find?', *American Economic Review* **110**(4), 1104–44.

Dinopoulos, E. and Thompson, P. (1998), 'Schumpeterian growth without scale effects', *Journal of Economic Growth* **3**(4), 313–335.

Greaves, H. (2019), 'Climate change and optimum population', *The Monist* **102**(1), 42–65.

Jones, C. I. (1995), 'R&d-based models of economics growth', *Journal of Political Economy* **103**(4).

Jones, C. I. (1999), 'Growth: With or without scale effects?', *American Economic Review* **89**(2), 139–144.

Jones, C. I. (2003), Population and ideas: A theory of endogenous growth, *in* P. Aghion, R. Frydman, J. Stiglitz and M. Woodford, eds, 'Knowledge, Information, and Expectations in Macroeconomics (in honor of Edmund S. Phelps)', Princeton University Press, pp. 498–521.

Jones, C. I. (2005), Growth and ideas, *in* P. Aghion and S. N. Durlauf, eds, 'Handbook of Economic Growth', Vol. 1B, Elsevier, pp. 1063–1111.

Jones, C. I. (2016), 'Life and growth', *Journal of Political Economy* **124**(2).

Jones, C. I. (2022), 'The end of economic growth? Unintended consequences of a declining population', *American Economic Review* **112**(11), 3489–3527.

Jones, C. I. (2024), 'The a.i. dilemma: Growth versus existential risk', *American Economic Review: Insights* . Available at: https://web.stanford.edu/~chadj/existentialrisk.pdf.

Klenow, P., Jones, C. I., Bils, M. and Adhami, M. (2023), 'Population and welfare: The greatest good for the greatest number'. Available at: https://web.stanford.edu/~chadj/popwelfare.pdf.

Lawson, N. and Spears, D. (2023), 'Population externalities and optimal social policy', *Working Paper* . Available at: https://drive.google.com/file/d/1xap7pviPWAwa54GToE9_kWsXOmxxZ_4v/view.

MacAskill, W. (2022), *What We Owe The Future: The Sunday Times Bestseller*, Simon and Schuster.

Ord, T. (2020), *The Precipice*, Hatchette Books.

Ord, T. (2024), 'Shaping humanity's longterm trajectory'. Available at: https://web.stanford.edu/~chadj/slides-popwelfare.pdf.

Rees, M. (2003), *Our Final Hour*, Hatchette Books.

Romer, P. M. (1986), 'Increasing returns and long-run growth', *Journal of Political Economy* **94**(5), 1002–1037.

Romer, P. M. (1990), 'Endogenous technological change', *Journal of Political Economy* **98**(5, Part 2), S71–S102.

Segerstrom, P. S. (1998), 'Endogenous growth without scale effects', *American Economic Review* pp. 1290–1310.

Spears, D., Vyas, S., Weston, G. and Geruso, M. (2024), 'Long-term population projections: Scenarios of low or rebounding fertility', *Plos one* **19**(4), e0298190.

United Nations (2022), 'World population prospects 2022', *New York, NY: United Nations Department for Economic and Social Affairs* .

Young, A. (1998), 'Growth without scale effects', *Journal of Political Economy* **106**(1), 41–63.