Population Decline: Too Slow for the Urgency of Climate Solutions

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Abstract: Human activity generates carbon emissions. This fact has led many to conclude that declining fertility will improve humanity's climate outlook. We show, using an integrated climate economy model that compares alternative population paths, that this relationship is in fact extremely weak due to facts of timing. Near-term changes in fertility rates have only small impacts on the total population size for many decades, while emissions intensities of economic activity are projected to remain highest. Put differently, decarbonization is urgent relative to the slow pace of even the fastest plausible changes in the global population size. Even in futures with under-ambitious climate policy, the impact of current fertility on cumulative emissions will be small, unless there are significant emissions into the 23rd century. Low fertility is a false solution to climate change: the population impacts are too small and too slow.

Keywords: Population decline; climate change.

Introduction

A smaller global human population would produce fewer carbon emissions. This fact informs an important view in climate policy and science, which holds that reductions in population growth could be a key component of the efforts to mitigate climate harms (Bongaarts and O'Neill, 2018; Wynes and Nicholas, 2017; Conly, 2016; Project Drawdown, 2020). Though it is widely accepted that a smaller population would benefit future generations by mitigating climate change, this account is incomplete, because it ignores important facts of magnitudes and timing of population changes relative to changes in emissions intensities.

Here, we use DICE, a leading climate-economy model designed to weigh the economic costs of climate damages (Nordhaus, 2018), to compare the temperature benefits of a projected global *Depopulation* to an alternative path of global population *Stabilization*. *Depopulation* builds from and extends the UN World Population Prospects 2022 Medium projection (United Nations, 2022). *Stabilization* is a constructed counterfactual meant to illustrate the impacts of avoiding human depopulation. This scenario sets all below-replacement fertility rates to replacement immediately (and has now-high-fertility countries converge towards replacement but no lower), generating a stable, large, long-run population.

DICE can be used to estimate the industrial emissions of different population sizes through the additional economic activity it expects from a world with more workers and consumers. In other words, DICE makes rigorous the population to economic production to emissions channel that is invoked to support the claim that smaller populations would be environmentally beneficial. A climate-module within DICE then translates cumulative emissions to projected temperature increases in a way that is consistent with standard climate models.

We use this model to compare temperature pathways over the next two centuries across the two population paths we consider. Despite large differences in long-run population sizes of these paths, the difference in long-run temperatures is very small. For example, these population paths differ by about 6 billion people by 2200. And yet, even under current policies that lack rapid decarbonization, *Stabilization* relative to *Depopulation* yields only a small difference in temperature increase (relative to pre-industrial) by 2200: 4.30°C versus 4.24°C, respectively. We also compare temperature differences across extremely optimistic and pessimistic climate policy scenarios, scenarios with much more rapid depopulation, and using alternative assumptions about population-emission elasticities and emissions-temperature relationships. In each of these different approaches, the effect of changing population growth rates on long-run warming is limited.

Why do we find such small effects, while others claim that there would be large greenhouse gas (GHG) reductions from population reduction? One straightforward reason is the speed of population change. Even immediate, large changes to fertility rates result in a global population that is only about 10% larger by 2100 when fed through a proper cohort-component model. Population change of this magnitude cannot make a large difference to cumulative emissions this century. This qualitative point has been made before (see e.g., Bradshaw and Brook, 2014; Lutz, 2023)—what we contribute is a quantitative accounting of plausible temperature effects across different decarbonization pathways, demonstrating precisely how little is at stake in the most likely futures.

A second, more subtle, difference is that our model accounts for the interaction between decarbonization progress and population change that is often ignored.[1] To see this contrast, consider an influential analysis by the climate research group Project Drawdown (2020). They study a pathway that achieves net-zero emissions by 2050, while at the same time

[1] In an insightful comment, van Basshuysen and Brandstedt (2018) mention the possible importance of this interaction, without formal analysis.

suggesting that a reduction in population sizes *in 2050* is an important component of this success. A statement like that makes little sense in the fully specified model that we employ: If economies successfully achieve per-person carbon-neutrality by 2050, then the size of the population in 2050 has exactly zero effect on the amount of carbon emitted. In this way, our findings extend and strengthen existing claims that population change cannot be a core mitigation strategy (e.g., Budolfson and Spears, 2021). Efforts to decarbonize the global economy will succeed or fail independent of population trajectories.

Inputs: Constructing Alternative Population Paths

A population path for our purposes specifies, for each five-year step, the total count of people. We focus our analysis on two main paths: a depopulation scenario and an alternative in which the global population stabilizes. These are used as inputs into the DICE model to evaluate impacts on long-run temperatures. We do not intend these paths to be detailed predictions. Instead, they are meant to be broadly representative of two contrasting abstract scenarios for the demographic future.

The first path, *Depopulation* is broadly consistent with demographers' central, consensus projection of the demographic future (United Nations, 2022; KC and Lutz, 2017; Vollset et al., 2020; Basten et al., 2013): Fertility rates worldwide will converge to below-replacement levels and global population growth will become permanently negative in the early 22nd century. The *Depopulation* path is the UN Medium projection until 2100, when that projection ends (United Nations, 2022). We mechanically project further (negative) population growth, guided by Basten et al. (2013) and Spears et al. (2023), the latter of which is a companion paper detailing the long-term decline scenario studied here. The growth rate falls by the same approximate rate of change as in the UN Medium projection for "Lower-middle-income countries" in 2100. Eventually, the global fertility rate converges to 1.66, the current TFR in the United States.

The second path, *Stabilization*, represents a possibility in which low-fertility societies (instantly) transition to replacement fertility today, so that there is no long-run decline in population size. We aim to assess the claim that a scenario of enduring below-replacement fertility will have benefits for the climate, making this contrasting scenario of immediate and enduring replacement-rate fertility a natural comparison. And, as we discuss below, many women in low-fertility societies report to surveyors that they would prefer to have approximately replacement-level fertility, in an ideal context (Sobotka and Beaujouan, 2014; Gietel-Basten, 2019). The *Stabilization* path is made by combining two UN projections: the Instant Replacement variant for High-income, Upper-middle-income, and Lower-middle-income countries according to World Bank income groups, and the Medium variant for Low-income, and No-income-group-available countries (so these latter two country groups have the same path to 2100 in *Stabilization* and *Depopulation*). After 2100, population growth stabilizes: countries that were not already at replacement rate by 2100 converge to this fertility rate, and total population size reaches about 13 billion in the 23rd century.[2]

While outcomes under *Stabilization* versus *Depopulation* will be our main comparison, we also include a scenario of *Rapid Depopulation* that extends the Low variant of the UN projections. This scenario is also meant only to be illustrative; it allows us to highlight that even an immediate worldwide drop to extremely low fertility rates can result in only small quantitative differences to warming on likely decarbonization paths.

Figure 1 shows how the population paths diverge over time. It plots *Stabilization*, *Depopulation*, and *Rapid Depopulation* from the present through 2200. The figure shows that a large difference in fertility rates now leads to large differences in eventual population size, but the paths do not diverge in a quantitatively significant way for many decades.

[2]The data and replication materials to this paper include a fully interactive worksheet with data that constructs our *Stabilization* and *Depopulation* paths from UN World Population Prospects.

This is especially true for *Stabilization* and *Depopulation*.

Evaluation Method: A Standard Integrated Climate Assessment Model

The population paths described above are used as inputs in an integrated climate assessment. We characterize the emissions and temperature harms of a larger population using the same models and parameters that have been used to calculate the social cost of carbon and inform environmental policy regarding the value of future damages from greenhouse gas emissions. Our focus is on climate harms, rather than other potential environmental harms coming from a larger population, because of its distinction as the foremost environmental challenge of our time.

We evaluate temperature changes with DICE (Nordhaus, 2018), the most widely used climate-economy model—specifically the DICE 2016 update (Nordhaus, 2017). Fundamentally, DICE combines three features: (a) a model of economic growth where labor and capital determine production, (b) a reduced-form representation of greenhouse gas (GHG) emissions, (accumulated) GHG concentrations, and temperature consequences, and (c) a damage function that translates temperature changes to future losses of economic well-being. Here, we focus only on components (a) and (b), tracing the emissions and temperature consequences of human population sizes and human activity.[3]

DICE's key equations that govern the flow-through from population, N, $\rightarrow$ economic

[3] All data, code, and replication materials are available at `https://github.com/...` [anonymized for peer review]. The model used in this paper is a special case of a more general model that we develop and present in prior research XXX [anonymized for peer review].

production, Y, $\rightarrow$ emissions, E, $\rightarrow$ warming, T, take the following form.

$$Y_t = A_t N_t^{\gamma} K_t^{1-\gamma} \tag{1}$$

$$E_t^{ind} = (1 - \mu_t)\sigma_t Y_t \tag{2}$$

$$E_t^{land} = \sigma_t^{land} N_t \tag{3}$$

$$T_t = g(E_t, E_{t-1}, \ldots), \text{with } E_t = E_t^{land} + E_t^{ind} \tag{4}$$

Economic production is a function of the size of the workforce (which scales with the size of the population), economic capital (e.g. buildings, computers, roads, etc.), and a measure of economic efficiency that exogenously grows over time, A. The fact that the exponents on labor and capital sum to one indicates that if the economy doubled each of these factors, production would double. Capital accumulates according to total savings in the economy, which will increase in the size of the population. So, in the long-run a doubling of the population will approximately double the capital stock, which will result in a doubling of economic activity.

The amount of industrial emissions produced is a linear function of total economic production, Y_t, holding fixed the emissions-intensity of output, σ_t, and the rate of mitigation, μ_t. In other words, for a given emissions-intensity and climate policy, doubling output in a period doubles emissions in that period. The emissions-intensity of output, σ, exogenously declines over time. As we demonstrate below, σ declines slowly enough that in the absence of mitigation efforts, emissions remain positive well into the 23rd century. The climate policy variable that prevents such an outcome is μ; it can be optimized by the model (as is typically done in applications of DICE) or selected by the researcher to demonstrate the implications of different paths for mitigation rates (as we do). Similarly, land-use emissions, E^{land}, scale with the size of the population, but without the opportunity for mitigation.[4]

Finally, there is a mapping, g, from the entire history of emissions, $E_t, E_{t-1}, \ldots$, to temperatures, T_t. We omit all of its equations, but note that it is based on a dynamic model with 3 sinks for carbon (deep oceans, upper oceans and the atmosphere). Moreover, it translates radiative forcings from carbon in the atmosphere to warming based on mainstream estimates of the equilibrium climate sensitivity parameter. Importantly, given complications associated with simplifying the atmospheric and climate modules for tractable economic applications, we demonstrate later that none of the results depend on any DICE-specific atmospheric assumptions. The small difference in warming comes from a small difference in emissions, which comes from the long delay in population size changes.

There are other economic equations in the model that we omit for brevity—they are not relevant for estimating the population-warming relationship. For example, there is an economic cost paid for mitigating emissions at some rate μ, and some economic output is lost to climate damages each period based on the level of temperatures in that period. These are important for estimating long-run living standards under different climate policy paths, but not for estimating the level of warming.

To study the climate costs of population paths, a climate policy scenario must be specified (i.e., a path for μ_t). That is, across population scenarios we hold fixed the emissions intensity of GDP—accounting for both technological advances and emission-control policies—and ask whether population differences alone impact long-run temperatures. Rather than focus on a single scenario, we report results that span a wide range of possibilities, to highlight the interaction between climate policy and population effects. In our baseline case, we assume a path of mitigation rates calibrated to global emissions in

[4]Technically, DICE sets land use emissions to be entirely exogenous. To avoid understating the emissions impact of population sizes, we instead scale these emissions up or down by relative increase (decrease) in population sizes.

2030, 2050 and 2100 under the current policy trajectory estimates in Ou et al. (2021). These estimates assume that new policies are implemented at the same (slow) rate which has been observed to date, such that international targets are badly missed, but by the end of this century there are substantial reductions in emissions via these slow policy roll-outs and technological progress. Because some may view even the prospect of significant reductions in annual emissions by 2100 as unduly optimistic, we also consider an extremely "low ambition" policy environment, which yields end-of-century warming of more than 4°C, similar to RCP 8.5. This low ambition scenario is significantly worse than climate experts now expect and so a conservative case to study (Hausfather and Peters, 2020). We also study a very ambitious climate policy scenario for a complete understanding of the relevant interactions. This allows us to speak directly to the possibility that population decline can usefully complement efforts to keep warming near international targets as proposed by Project Drawdown (2020), among others.

Results: The Timing of Population Changes and of Emissions Reductions

Our main results are displayed in Figure 2. The middle row depicts emissions and temperature outcomes under current policy estimates (Ou et al., 2021). The top row depicts outcomes under very ambitious climate policy; the bottom row under a failure to control emissions. Each panel compares *Stabilization*, *Depopulation* and *Rapid Depopulation* with the right-hand panels denoting the differences in long-run temperatures (denoted Δ) by 2200 between *Stabilization* and *Depopulation*.

Consider first the middle row of Figure 2. Under a current policy level of ambition, emissions are almost indistinguishable in the next several decades between the two main population paths. They eventually diverge to be visually separable in the graph, but the differences are small. Even the emissions pathway under *Rapid Depopulation* lies just under the other two, implying a small difference in cumulative emissions. Consequently, global temperatures are only slightly increased under *Stabilization* relative to *Depopulation*: 4.30° versus 4.24° in 2200 under current policy. With *Rapid Depopulation*, temperatures still reach 4.05°, a less than 5% reduction in temperature increase relative to baseline.

The top and bottom rows highlight the interaction between emissions reductions and population changes. In a world of unmitigated emissions that persist beyond 2200, total warming is 6.49° versus 6.14° between *Depopulation* and *Stabilization*. Warming of 5.43° results under *Rapid Depopulation*. This assumed policy failure has nothing to do with the particular population paths evaluated here—we study it only as an extreme case. The 0.35° difference between *Stabilization* and *Depopulation* is larger than the difference under current policy, but small relative to the size of total warming. An additional one-third of a degree would not be the policy relevant focus in such a catastrophic climate future. Even near-term rates of population decline that generate global population sizes below 3 billion by 2200 prevent only about 0.7° of the expected 6° increase on this emissions path. So, fertility decline as extreme as seems plausible generates a reduction that is significant in this case, but still relatively modest compared with the level of overall warming in these catastrophic scenarios.

Alternatively, in a future where emissions are controlled quickly in an effort to meet international targets, there is no perceptible difference between any of the three population scenarios (top row of Figure 2). The invariance of warming to population in this case is perhaps the most relevant takeaway for those interested in averting unacceptably high warming. If the goal is to avoid 3°+ of warming, or anything less than that, population change cannot play even a small role.

How is it possible that a difference of about 6 billion people by 2200 (*Depopulation* versus *Stabilization*) yields such tiny temperature reduction benefits? This result, anticipated without our quantitative integrated assessment by Bradshaw and Brook (2014) and Lutz

(2023), reflects facts of timing discussed earlier. The first fact is that population *size* (a stock) is slow-changing over the span of a few decades, even if fertility *rates* (flows) change fast. In post-demographic-transition populations, the new, larger cohorts make up a very small fraction of the total population at first. So the size of the population is only 12% larger under *Stabilization* in 2100 despite that it is 87% larger by 2200. Consequently, the yearly flow of CO_2-equivalent emissions would be 11% larger in 2100 under *Stabilization* than *Decarbonization*, a finding consistent with the population elasticity of emissions of about one estimated by O'Neill et al. (2012).

The second fact arises from technological and policy progress: Emission reduction efforts—underway in many countries today—are projected to continue to advance in the coming decades. Total emissions are declining soon after 2050 in the current policy scenario and a little after 2100 under the low ambition scenario. As noted, even the current policy scenario is low-ambition relative to shared international climate goals. But importantly for the conclusions here, this shows that our results do not rely on assuming unrealistically fast rates of decarbonization. In even these high-warming scenarios, most of the population size increase occurs at a time of significantly less emissions per person than today. This carries the implication that increases in fertility rates today would generate less warming than a similar, counterfactual increase decades ago. In other words, the human population that will have existed in the 400 years from 1700–2100 will have generated much more carbon emissions than the population in the subsequent 400 years, under plausible (even very pessimistic) population and mitigation scenarios.

These facts fully account for the difference between our findings and other prominent estimates. Take as an example the analysis of a leading climate research group, Project Drawdown; they claim to demonstrate that population decline is one of the most effective methods of reducing emissions this century.[5] The first issue with this analysis is that the

[5] See `https://drawdown.org/solutions/table-of-solutions`. The table can be sorted by

change in population sizes that they study is unreasonably fast. Their high- and low-population scenarios differ by 1.3 billion people in 2050. In contrast, *Stabilization* and even *Rapid Depopulation* differ by only 0.9 billion in 2050. And our own paths differ by more than the range of the UN's upper- and lower-95% confidence intervals—we study these paths *because* they represent the largest population divergence that seem plausible. Yet, the Project Drawdown findings rely on a difference nearly 50% larger than this. Adding to the implausibility, they claim that this sort of change in the global population could be brought about by modest interventions, such as eliminating gender gaps in education and increasing contraception access. These are welcome improvements, but would have limited effects on near-term, global fertility rates and population sizes.

Second, and more importantly, they ignore the interaction between reductions in per person emissions and the effect of population size. Their estimates of emissions reductions coming from population decline are quantitatively independent of the assumed mitigation scenario. Regardless of whether net-zero is reached by 2050 or 2100, they estimate the exact same effect of the exact same population change. Figure 2 demonstrates that this is incorrect: population size *scales* total emissions, it is not an independent additive factor. Put simply, an additional person in a world of clean electricity contributes less carbon than an additional person in a world reliant on coal and other fossil fuels. In our implementation of a scenario similar to the ambitious scenario Project Drawdown focuses on, where humanity achieves net-zero by around 2050 (top row of Figure 2), there are *no* perceptible effects of population change on long-run warming. This speaks decisively against the finding that population change can help promote near- or medium-term drawdown.

This interaction can also be understood by considering the projected carbon footprint of a single human life added to the global population at each point in time. Figure 3 illustrates

amount of GHGs averted. In "Scenario 1" (roughly in line with 2°C temperature rise) family planning is the 3rd most potent reducer of GHGs, after "reducing food waste" and "plant-rich diets".

the declining emission intensity of children born in any particular year throughout their lifetimes under our baseline scenario. Instead of changing the path of fertility rates, we simply add one new child to the population and track their lifetime emissions. We assume that this individual exhibits average emissions behavior in each year and lives for the 80 years following their birth. Figure 3 shows that the carbon footprint of an additional baby is falling towards zero and is already lower than it was in most of the 20^{th} century, according to projections of annual per person emissions coming from our model. The temperature impacts of population stabilization are small exactly because emissions are projected to be much smaller by the time that large differences emerge between the *Stabilization* and *Depopulation* paths. In short, greenhouse gas emission intensity is changing *too quickly* to be a quantitatively important cost of any plausible, slow-moving alternative to *Depopulation*. This fact about timing would limit the climate costs of *Stabilization* even if climate damages or the emissions elasticity of population size are much larger than DICE assumes and even if climate policy is less ambitious than our baseline assumes.

Discussion and Conclusion

To emphasize: we are identifying the implications that follow from combining consensus demographic projections (or minor extensions of them using standard cohort component methods) with standard components of integrated climate assessment models. Therefore, we inherit the well-studied advantages and limitations of these components.

To gauge sensitivity to these features, Figure 4 presents the core results of additional robustness checks, each from a different set of modifications to the baseline model. The output is summarized in a table of relevant model differences, as well as a histogram of temperature differences between *Stabilization* and *Depopulation* under these various modifications. We cross each of these modifications with the three climate policy scenarios in Figure 2. First, we replace DICE's atmospheric representation by the Finite Amplitude Impulse Response (FaIR) model (Millar et al., 2017). FaIR is an effort by the atmospheric modeling community to produce a representation of the Earth's climate system that is realistic, but computationally simple enough to be used for exercises like the one we perform. It remains complex in absolute terms, so we direct readers to Millar et al. (2017) for a full description of model equations. We note here that FaIR was recommended for use in integrated assessments in a report by the National Academies about incorporating frontier insights from the climate-modeling community into future social cost of carbon estimates (National Academies, 2017). Second, and for conservatism, we mechanically increase the emissions elasticity of population to be larger than DICE assumes. In short, DICE assumes that emissions only increase when GDP increases, because emissions come from economic activity. However, economic activity does not immediately scale with increases in population size (economic capital accumulate with a lag, for example). This modification allows for emissions to increase immediately with population growth, in line with estimates documenting a straightforward multiplicative relationship between population size and aggregate emissions (O'Neill et al., 2012).

In all cases, the key pattern of results remains: Changes in fertility rates today would cause large long-term changes in population size, but only small differences in long-term warming. It is not surprising that the results do not depend on the specifics of DICE once Figures 1 and 2 are taken in conjunction. The results follow from the deep fact that, if humanity is to avoid worst-case climate scenarios, per person emissions must fall before population sizes have responded in any significant way to near-term fertility changes. DICE is merely one way to discipline a future path of per person emissions through its economic module, but any method for generating estimates of future per person emissions that do not remain high well into the 23rd century would result in the conclusion that the atmospheric stock of GHGs—and therefore warming—are relatively invariant to demographic change.

We note several caveats and limitations to this analysis. First, DICE is a global integrated assessment model, so our model omits geographic heterogeneity. To isolate the effects of population size—rather than compositional change—the population is treated as homogeneous individuals, who each contribute an equal amount of economic production and carbon emissions within a given time period.[6] Our purpose here is to establish the global facts, including that population size changes are slow and predictable relative to the urgency of emissions reduction. Like the other modeling variants examined in Figure 4, substituting a regional model would tweak our exact quantitative projections but would not alter our core qualitative results. Second, we have ignored here the well-established role of population growth and population size in increasing the speed of technological developments and turnover of infrastructure (Jones, 2022). It is plausible that a larger, more dynamic economy will reduce its emissions intensity faster than a stagnating, aging economy. If present, this force would further mitigate the small temperature differences that we find, though it is unlikely to fully offset the small increase (Kruse-Andersen, 2023).

A larger population would also have environmental impacts beyond climate change, including for biodiversity, non-human animals, and non-carbon air and water pollution. Our main analysis does not address these. Here, we focus on whether there are important climate benefits of trends towards lower fertility, because climate change receives prominence in scientific and policy conversations as the key environmental challenge of our time. Nonetheless, these other topics are important and we look forward to future research that can speak to these additional issues.

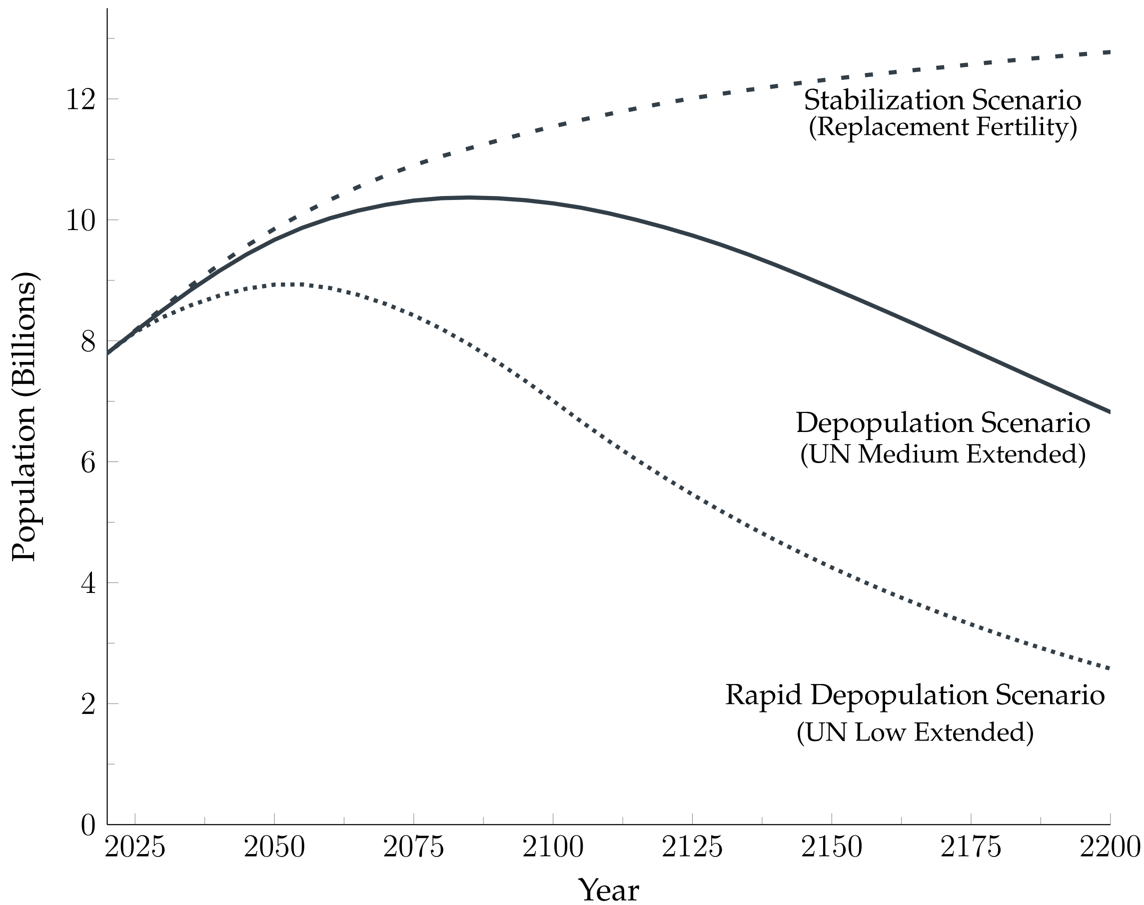
[6]However, the characteristics of this globally average person depends on the projected distribution of population within each period. For example, because future population growth will be concentrated in Sub-Saharan Africa, the productivity and emissions of this globally-average individual are implicitly calibrated to shift to be more representative of this region as it grows. Our analysis holds fixed this assumption about composition, imagining a proportional increase in population across geographies in our hypothetical scenario.

Finally, the size of the population may itself influence the possibilities for successful socio-economic adaptations to a warming world. On the one hand, a smaller world population would be less threatened by diminished natural resources (Henderson et al., 2023). Likewise, if low fertility is correlated with higher levels of education, smaller populations will have a (per person) human capital advantage (Lutz, 2023). On the other hand, a larger population has more hands available to deal with the fallout from climate change, and more innovators to develop novel adaptation solutions (see again Jones, 2022). As a straightforward example, building sea walls around vulnerable coastal cities will be cheaper per resident for larger populations. Moreover, the production of a fixed quantity of industrial *negative* emissions will be cheaper per person in a world with a larger population (Budolfson et al., 2023). Through scale alone, a larger labor force will have more economic resources to build and maintain carbon capture and storage facilities, among other negative emissions technologies that may be feasible in the coming centuries. While an important issue for future research, it is beyond the scope of this paper to determine the global population size that would be optimal for dealing with climate change.

Global depopulation is projected to begin within the lifetimes of people alive today. Once population growth becomes negative, no currently foreseen demographic force would reverse the path. Large policies might. The most plausible, powerful, and ethical policies would be those rooted in reproductive justice: the right to maintain bodily autonomy, have children, not have children, and parent children in safe and sustainable communities (Hartmann, 2016). Survey evidence from many low-fertility populations reports that, if less constrained, many women would prefer to have more children, roughly at replacement-fertility levels (Sobotka and Beaujouan, 2014; Brinton et al., 2018; Beaujouan et al., 2019; Gietel-Basten, 2019). Our findings suggest that, if investments in human development, gender equality, labor markets, support for children and care work, and assisted reproductive technology could support women's ability to achieve this preference—if they choose to do so—then such investments would generate only very small increases in long-run temperatures (although we conjecture that such investments must be substantially more ambitious than familiar policies) (Gietel-Basten, 2019; Adserà, 2017). A minimal reading of the policy implications of our result is that the weak link between population size and climate outcomes offers yet one more reason why fertility policy has no place in discussions of climate policy.

Our study shows that even when comparing changes in population paths larger than any known policy or system of parental support could produce—from *Depopulation* to *Stabilization*—the temperature impacts are small. Even immediate changes in fertility rates have only small impacts on the total population size in the near-term, while emissions intensities of economic activity remain highest. If populations are not importantly different this century, by which point decarbonization is projected to be more advanced, then there is little space for current fertility rates, or changes to them, to have large climate ramifications. Low fertility is a false solution to climate change: It generates changes that are too small and too slow.

Figure 1: Population *Stabilization* versus *Depopulation*: A large difference in fertility rates now leads to large difference in population size next century



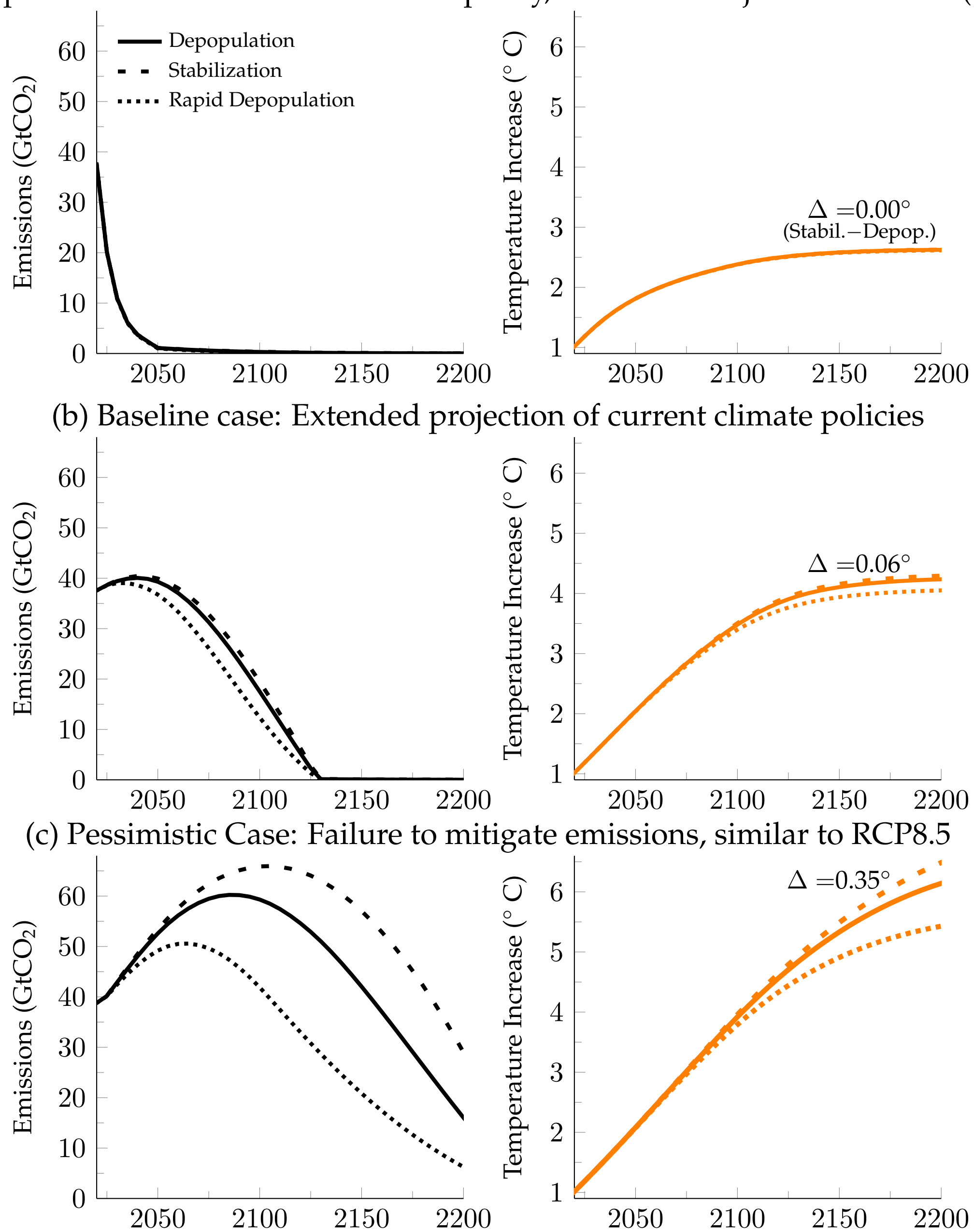
Notes: *Depopulation* and *Stabilization* population paths are derived from United Nations (UN) World Population Prospects 2019 projections. UN projections are available until 2100. *Depopulation* follows UN Medium until 2100 and then are extended to match demographic facts for low-fertility populations (United Nations, 2022; Basten et al., 2013; Spears et al., 2023). *Stabilization* combines Medium for Low-income and Lower-middle-income countries and Instant Replacement for High-income and Upper-middle-income countries. *Rapid Depopulation* extends the UN Low variant for all countries.

Figure 2: Climate models tell us that future population size matters little for temperatures

(a) Optimistic case: Ambitious climate policy, similar to Project Drawdown (2020)

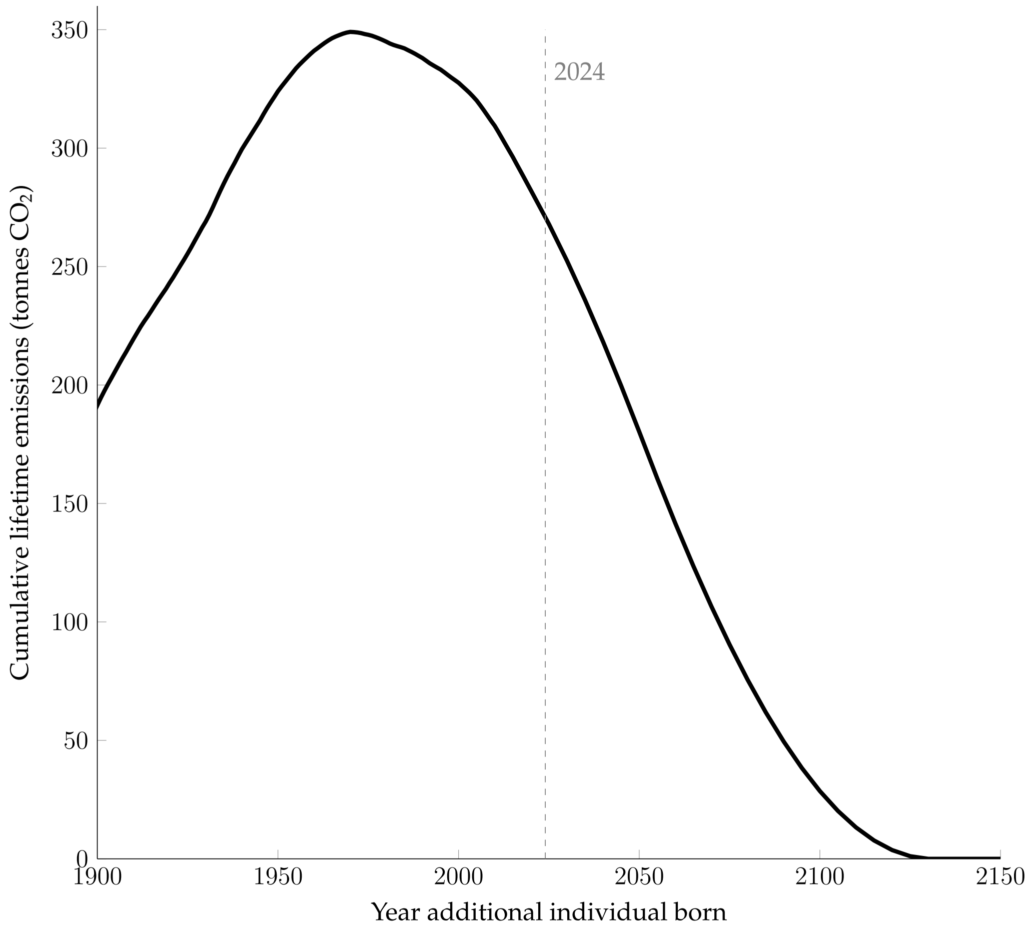
(b) Baseline case: Extended projection of current climate policies

(c) Pessimistic Case: Failure to mitigate emissions, similar to RCP8.5



Notes: Projected emissions (left) and temperature increases (right) from DICE2016 in across the different population scenarios studied. The middle row implements a calibration to estimates of current policy (Ou et al., 2021). The top row implements an extremely ambitious path of mitigation rates that has the world at net-zero just after 2050. The bottom row assumes a failure to limit emissions for hundreds of years, generating warming similar to the well-known RCP8.5 scenario.

Figure 3: The carbon footprint of an added baby is falling towards zero



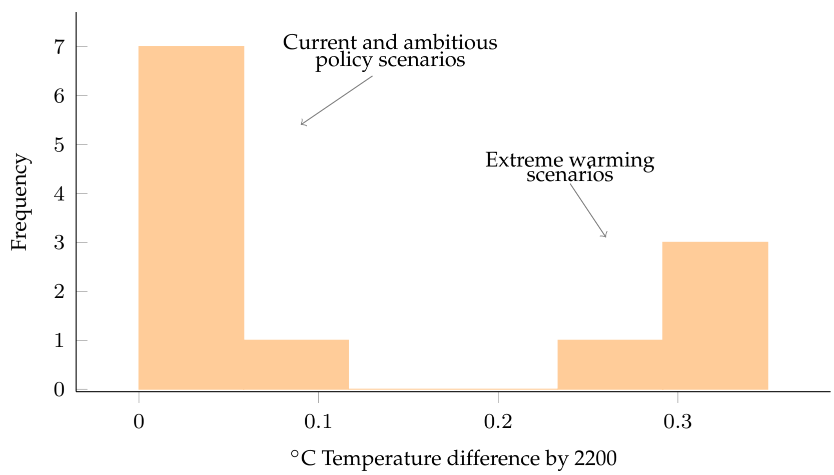
Notes: Additional emissions from (exogenously) adding one additional child to the planet in each of the given years. We assume an 80 year lifespan, where this child produces (global) average annual per person emissions in each of these years. So, for example, the value for 1950 represents a baby born in 1950 who lives until 2030. For historical per person emission values we use OurWorldinData.org; for years 2020 and beyond we use our baseline current policy scenario that generates the middle panel of Figure 2. Impact trends towards zero because emissions per person are projected to decline to zero by 2125.

Figure 4: Differences in warming across population scenarios is small with alternative model specifications

(a) Model runs and their long-run warming

	Climate Policy	Climate Representation	Population-Emissions Elasticity	Total Warming by 2200	Difference in Warming
1	Very Ambitious	DICE	DICE	2.62	0.00
2	Very Ambitious	DICE	1.0	2.62	0.00
3	Very Ambitious	FaIR	DICE	2.54	0.00
4	Very Ambitious	FaIR	1.0	2.54	0.00
5	Current Policy	DICE	DICE	4.24	0.06
6	Current Policy	DICE	1.0	4.23	0.07
7	Current Policy	FaIR	DICE	3.64	0.05
8	Current Policy	FaIR	1.0	3.62	0.05
9	No emissions control	DICE	DICE	6.14	0.35
10	No emissions control	DICE	1.0	6.10	0.37
11	No emissions control	FaIR	DICE	5.54	0.41
12	No emissions control	FaIR	1.0	5.47	0.44

(b) Histogram of temperature differences



Notes: Resulting change in temperature across 12 model specifications: 3 climate policy scenarios × 2 climate modules × 2 assumptions about population emissions elasticity. Climate scenarios span very warm futures (as in Fig. 2), to scenarios where emissions are quickly and the world meets a 2° target. Climate modules include DICE's native module and FaIR Millar et al. (2017). Emissions elasticity assumptions include the implications in DICE and a mechanical implementation of unit elasticity, such that a 1% increase in population always leads to a 1% increase in emissions and consistent with O'Neill et al. (2012). Panel (a) provides the description of each model combination, as well as its total warming in the baseline *Depopulation* scenario, and the increase in warming that would result from those same assumptions with the additional population growth of *Stabilization*.

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