EARTH4ALL: WORKING PAPER #1

March 2023

People and Planet

21st-century sustainable population scenarios and possible living standards within planetary boundaries

A report from the Earth4All initiative to the Global Challenges Foundation (GCF) in response to GCF's research call, May 2021.

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The report is based on Earth4All modelling outputs produced by Jorgen Randers, Ulrich Goluke, David Collste and Sarah Mashhadi.

Earth 4All

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1. Introduction: Global Challenges Foundation request – and our interpretation

The Global Challenges Foundation (GCF) has raised the following questions for Earth4All to answer:

1. **To what extent** can humans exploit Earth's natural resources without threatening the sustainability of Earth's biosphere?
2. **To what extent** can humans increase natural resources (defined in question 1) through better management (for example circular economy practices), anticipated technological development and other changes in consumption and production, without lowering material standards of living?
3. **How many people** could Earth's biosphere support (as defined in question 1), with increased utility value, if everybody were living on the minimum level stated in the United Nations Universal Declaration of Human Rights article 25.1?
4. **How many people** could live sustainably on Earth – within planetary boundaries and accounting for increased average life expectancy – if the average standard of living exceeded the minimum level by 10, 20 or 30% respectively?
5. **If any or several of the answers** to the questions above is less than the current population, the question becomes: What are the most appropriate and important measures to reach a long-term sustainable global population, according to the best available scientific evidence?

In this report we summarise the results of our research on population. We provide estimates based on scientific evidence about quantifiable policy measures that can and will shape the future population trajectory, per main region in the world, into a long-term sustainable global population. We use these simulations to provide answers to all the questions raised by the GCF.

In general, our estimates for future population trends are substantially lower than UN mid and high projections, leading to a potentially more optimistic outlook on the relationship between population and sustainability. However, a quicker demographic transition brings its own challenges, particularly of inequality and ageing.

Before providing our answers to the questions raised by the GCF, it is necessary to contextualise our work within the ongoing broader efforts to forecast, simulate and understand long-term demographic developments, their drivers and consequences, in order to highlight the differences in assumptions and methods between them and Earth4All's and explain the corresponding underlying reasons.

2. Overview of main demographic approaches

In this section, we provide a general overview of the currently more-influential approaches to the question of global demographic trends simulation and an analysis of the observable methodological differences, in order to provide the foundations required to understand our Earth4All assumptions and methodological choices, and their relation to the aims we intend to reach.

2.1. UN approach to demographic modelling – statistics only

The UN approach to demographic modelling (UN, 2020) can be summarised as follows. First, the UN collects the best available demographic data, and augments it further through the application of analytical instruments addressing well-known weaknesses of official time series, such as missing migration data, inconsistencies among census practices and various biases affecting reporting of retrospective birth histories or lifetime fertility. These deficiencies are rectified through an iterative simulation process, resulting in an augmented-census dataset. Then, UN demographers proceed to calculate the 1950 base population using a Bayesian hierarchical model of population reconstruction (Wheldon et al., 2016), in order to develop a robust time trend of fertility and mortality rates. Key parameters are then adjusted by comparing reconstructed trends with augmented-census data, finally resulting in an estimate range for demographic trends up to 2100.

The main limitation of this approach is that it relies exclusively on demographic data to extrapolate a historical trend. This does not shed any light on the *causal* mechanism generating the trend itself and its evolution over time, i.e. what causes birth and death rates to deviate from historical trends and change into the future of a given society or region. If we assume that the underlying unknown causal structure persists *without* any significant change in the future, then the projected population estimates will be reliable. Considering that the estimates are projected up to 80 years in the future, however, it is unlikely that no significant changes in the causal structure would take place. It could be argued that such changes may not significantly affect the projected trend, and that the actual results will still fall within the projected confidence interval range; however, without any exploration of the causal mechanisms and their relative relevance, this hypothesis lacks any means of gaining significant support. Furthermore, available historical demographic data tell us that significant changes in demographic regimes do take place (Lee, 2003), and that historical trends can be rapidly reversed by both socio-economic and natural changes (Dyson, 2010). To assume that no such changes will take place in the coming decades is quite bold, especially in light of the significant sustainability challenges that climate change entails.

Certainly, the UN is conscious of these limitations. However, its approach is unlikely to change due to the necessarily neutral political stance that an organisation such as the UN is required to maintain in order to fulfil its mandate. To endogenise fertility, mortality and/or migration dynamics would imply the integration of causal mechanisms reflecting societal structures and political decisions at national levels. Analytical necessity requires such mechanisms to be simplified in comparison with the exceeding complexity of the reality. Consequently, it would be easy to portray the choice of variables used, no matter their actual composition, as politically motivated, and therefore inconsistent with the UN's overall mission. For all its limitations, the approach taken by the UN has the merit of minimising dissent and focusing the debate on purely demographic and methodological matters. For the purpose of providing meaningful answers to the GCF's questions, however, we must go beyond the UN approach and integrate causal mechanisms, contentious as they might be.

2.2. Wittgenstein Centre approach – education first

The Wittgenstein Centre approach, sponsored by the European Union, represents a key step towards the integration of causal mechanisms within demographic modelling. Its population projections are based on a multidimensional generalisation of the cohort-component projection model, projecting populations by cohorts based on assumptions regarding the connection between future fertility, mortality, migration and education trends (KC et al, 2010). The addition of educational attainment as a third demographic dimension alongside age and sex is motivated by the assumption that the relationship between education and demographic outcomes is both real and causal in nature, with education affecting fertility and mortality trends (Lutz & Goujon, 2001). Female education has long been identified as one of the most powerful determinants of fertility rates at the individual level (Cleland, 2010). Every degree of female educational attainment reduces aggregate fertility rates; this relationship has been observed to hold at all stages of development, and from a wide range of cultural traditions. However, the strength of the effect varies depending on the national context: generally speaking, lower educational attainments are more effective at reducing fertility rates in developing countries. Over time, however, the effect of education differentials on fertility rates is supposed to converge on values reflecting the situation of higher-income countries. On average, compared with post-secondary education, fertility rates are 42% higher for women with no education, 35% for women who completed primary school, and 14% higher for women with secondary education (KC and Potančoková, 2013). Mortality differentials across different educational attainments are also robust across a wide range of different nations (Lutz et al., 2007). Assuming secondary education to be the norm, the data show an average difference in life expectancy of three years less in the no-educational category, two years less in the primary category, and two years more in the tertiary category.

Functional causality is claimed on the basis of a strong empirically observed association between the educational attainment and demographic trends, and a plausible narrative about the mechanisms through which one force influences the others. Educational attainment reduces both fertility and mortality rates. The model simulates this by calculating educational attainment-specific mortality and fertility rates for every cohort. Over time, the educational differentials across geographical regions are assumed to converge, eventually leading to a more general demographic convergence on a global scale. This convergence, however, is predicated on specific assumptions regarding patterns of socio-economic developments, creating space for alternative, less-optimistic scenarios, characterised by lower education, and consequently higher fertility and mortality rates. Assumptions are necessary because the Wittgenstein model is a purely demographic model, lacking any means of endogenously simulating socio-economic and/or natural developments.

Despite the limited causal reach of the approach, which relies on a single causal mechanism – educational attainment – to explain global demographic trends, the Wittgenstein model illustrates the relevance that even limited causal demographic models have for policy development. Not only does the integration of educational attainment connect socio-economic and demographic developments, enabling the generation of alternative scenarios, it also creates the opportunity for policymakers to affect development trajectories by targeting the relevant mechanisms involved. The acceptance of the Wittgenstein model implies a prioritisation of global education efforts to accelerate the rate of convergence to a sustainable demographic equilibrium. The model also highlights, however, the weakness of causal argument. The demographic impact of educational attainment, while well documented, is partially related to the socio-economic impact of education on the life of the individual. If, for any contextual reason, education would cease to provide a channel for social mobility, its demographic impact may well be less pronounced than expected, with significant consequences for the validity of the model's predictions. Therefore, focusing on a single, albeit meaningful, variable may unduly narrow an analytical and policymaking focus.

2.3. Lancet model approach – adding health and contraception

The Lancet approach to demographic modelling (Vollset et al., 2020) represents a further development in the direction of causal argument. The Lancet study is explicitly critical of the acausal approach adopted by the UN, describing it as "sophisticated curve-fitting exercises" based on "arbitrary assumptions without uncertainty" and, in more subdued fashion, of the Wittgenstein Centre approach, "a blend of statistical models fit to past data and expert judgment on likely trends in fertility". It describes its own efforts, introduced as a significant advance over existing alternatives, as including a model for completed cohort fertility at age 50 years (CCF50) and age-specific fertility as a function of educational attainment and contraceptive-met need, a measure of the proportion of women in a population of reproductive age whose need for contraception has been met, combined with an all-cause mortality model and a model for net migration with uncertainty, all generating projections up to 2100.

The cause-specific mortality model includes three components: the underlying mortality, modelled as a function of the Socio-Demographic Index (SDI) and time; a risk factor scalar that captures the combined risk factor effects for specific causes; and an autoregressive integrated moving average model accounting for unexplained residual mortality. The fertility model estimates the average number of children born to an individual female from an observed birth cohort assuming she lived to the end of her reproductive lifespan (age 15–49 years) as a function of contraceptive-met need and female educational attainment. Finally, net migration rates are modelled as a function of SDI, death due to conflict and natural disasters, and the difference between birth and death rates. The model also includes an additional mechanism connecting demographic and socio-economic developments, as it calculates the impact on total gross domestic product (GDP) of expected changes in national and global age structures. While significantly different in structure from the Wittgenstein model, the estimates produced by the Lancet approach are not extremely different from their main competitors, as illustrated by Figure 1:

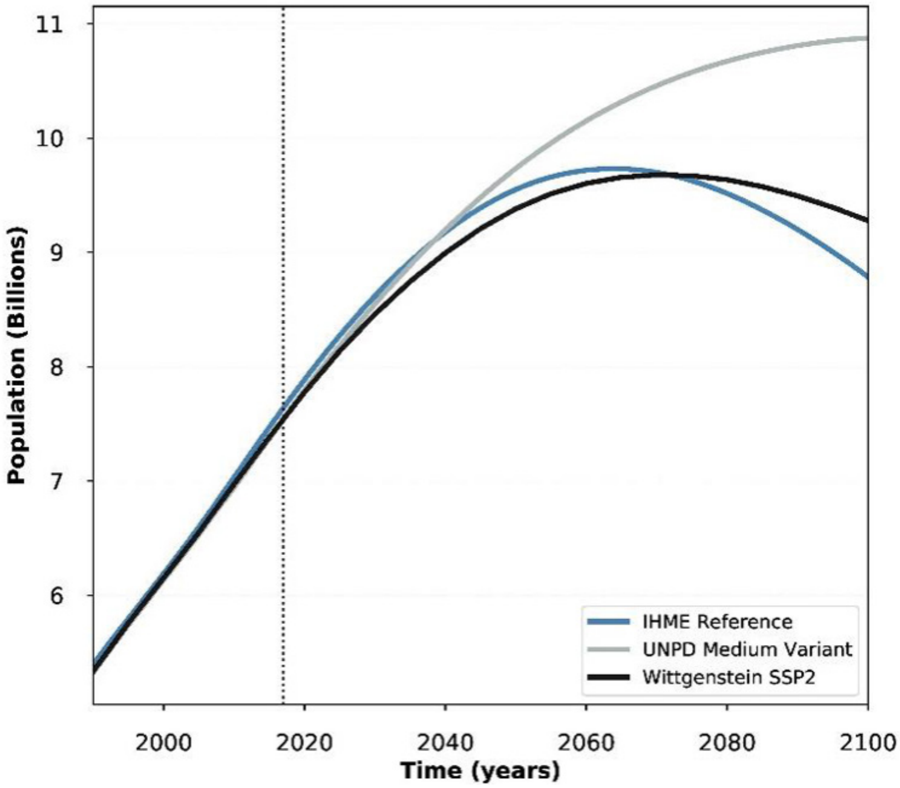


Figure 1: Comparing the UN (UNPD Medium Variant), Wittgenstein Centre (Wittgenstein SSP2) and Lancet (IHME Reference) demographic forecasts. Source: Vollset et al., 2020.

While both the Wittgenstein Centre and Lancet estimates are much lower than the UN's, due to the moderating impact of their causal mechanisms on fertility rates, the Lancet approach identifies an earlier demographic peak below 10 billion people to take place around 2060, followed by a much more pronounced global demographic decline. Describing this decline as inevitable, the authors argue that liberal immigration policies and pro-natal social policies will be key to sustaining GDP growth in the long term, and to ensuring the various economic, social and geopolitical benefits that come with stable working-age populations. While GDP per person will rise faster due to population decline, the actual growth rates will be significantly affected by demographic policies. Thus, the global demographic decline may be set in stone, but the demographic fate of each country remains their own to decide.

2.4. Influential integrated assessment model approaches – endogenous and exogenous solutions

Besides pure demographic models, population dynamics have been increasingly assimilated within Integrated Assessment Models (IAMs), due to their relevance in the evaluation of natural and socio-economic trends. In their review of the most influential IAMs of the time, Constanza et al. (2007) illustrate the most common approaches to demographic modelling in this context. Models such as the Dynamic Integrated Climate-Economy model (DICE) (the neoclassical model famously developed by Nobel Laureate Nordhaus in 1992), and the Integrated Model to Assess the Greenhouse Effect (IMAGE-1) (developed by the National Institute for Public Health and the Environment in Bilthoven, Netherlands), have integrated demographic trajectories as exogenously given, based on the most recent UN projections available. More complex models, such as IMAGE-2 and its successors, developed by the Netherlands Environmental Assessment Agency (Bouwman et al., 2006), integrated an explicit demographic module instead. Such modules, however, would usually be a simplified version of the UN cohort-component model, requiring three exogenous age-specific time series, namely, sex ratios, death rates and fertility rates (Court & McIsaac, 2020), thus representing a somewhat limited step towards endogenisation of demographic dynamics.

Furthermore, the extent to which a demographic module is integrated within the more general IAM structure varies. At one end of the spectrum, the IMAGE-2 demographic module serves only to provide the rest of the model with population data. The demographic module of TARGETS, a different IAM, instead includes feedback loops through the integration of a population health sub-model. At the other end of the spectrum, we find World3, a system dynamics model of the interactions between population, industrial growth, food production and limits in the ecosystems of the Earth, originally produced and used by the seminal Club of Rome study providing the foundations for the book *The Limits to Growth* (1972). World3 is also notable for its original modelling approach. Despite being based on a similar 5-year age structure, the model used is original rather than an adaptation of the UN cohort-component model. While the World3 solution does away with the need for three age-specific exogenous time series used by the UN, its complexity has been criticised as resulting in opacity regarding the driving mechanisms behind demographic processes (Court & McIsaac, 2020). This is a necessary consequence of the deep integration between the population module and the rest of the model. From this simplified overview, the following general considerations can be drawn.

IAMs require the integration of demographic data to generate estimates of future development pathways. The simplest solution, adopted by models such as DICE, is to integrate the best available estimates from existing demographic models in exogenous fashion. The exogenous approach is not without advantages. First, it simplifies the model's complexity, thus shifting the focus to other dynamics. Second, the reliance on advanced, well-established demographic projections provides broadly perceived credibility for the model's results. Third, since only demographic data is needed, it is possible to use different estimates with the same model, to evaluate the impact of different demographic assumptions on future developments. The major disadvantage of the exogenous approach, however, besides the complete reliance on the reliability of the assumptions used, is that it makes it impossible to model any sort of causal interaction between other model components and demographic processes.

While estimates based on different behavioural/policy assumptions can be used in the model, and the different results compared, the use of an exogenous demographic component is equivalent to the assumption that none of the mechanisms included in the IAM interact in any way with the demographic process. Given the broad range of dynamics included in IAMs, this is a significant limitation. It might be hypothesised that, given the long-term nature of demographic processes, interactions with other modules can be ignored without any significant losses in terms of estimation results. However, this hypothesis only holds for estimates extending a few decades into the future at best. Over several decades, even marginal changes to population trajectories can accumulate, leading to significant consequences. In short, IAMs aiming to support long-term scenario planning must include an endogenous demographic component. However, the endogenous approach is not without limitations.

The first limitation is that an endogenous demographic module still requires the introduction of significant assumptions. The most common approach – the integration of a simplified replica of the UN cohort-component model – relies on exogenous estimates of critical time series, such as sex ratios, death rates and fertility rates. If these key parameters are set exogenously, then the development pathway can exert only a very limited influence on demographic patterns, and vice versa. While simulating even limited causal interaction is a significant analytical improvement over the fully exogenous approach, the approach relies on potentially problematic assumptions. The model implicitly assumes that socio-economic development patterns, and their supporting policies, cannot significantly alter demographic dynamics, which therefore should be considered an immutable constraint.

To relax this limitation, it is possible to use different time series, corresponding to different demographic scenarios; for example, it is possible to simulate what would happen in case of a significantly lower fertility rate trajectory. This approach, however, either implies that demographic changes take place due to exogenous factors, thus neutralising the advantage brought by an endogenous demographic sector, or that the socio-economic conditions and costs inherent in such a shift can be calculated in advance, and thus similarly exogenously added to the model. While not unreasonable, this assumption is again questionable for long-time analyses. Furthermore, the hypothesis is at odds with the key concept behind most IAMs, namely that complex feedback loops dominate linear processes, and that therefore policy costs and consequences cannot be estimated in isolation.

The second limitation comes from attempts to move beyond the reliance on exogenous data and develop demographic modules able to endogenously replicate historical demographic time series and, it is hoped, future developments. This approach, shared by Earth4All, is based on a series of assumptions regarding the structure and parameters of demographic processes. A problem arises from the fact that there is no single consensus approach to the issue. For example, the augmented DICE model of Lupi and Marsiglio (2021) assumes population growth to be the result of the agents' optimal decisions regarding how many children to have, balancing the utility gained from having children with the cost of raising them.

This solution is based on two sets of assumptions. The first concerns the model structure, and amounts to assuming that aggregate demographic processes result from individual fertility choices, which can be effectively simulated as if they were economic utility intertemporal maximisation choices. The second set of assumptions concerns parameters governing key elements such as the utility gained from children, and its evolution through time. Of these assumptions, the first set is key. While changes in the second set of assumptions would result in potentially significant divergences in the resulting development pathways estimated by the model, rejecting the first set of assumptions would invalidate the entire family of models built on such foundations. This is especially problematic, given that there is no interdisciplinary consensus with regard to the most effective modelling approach for IAM demographic modules. Modelling fertility choices as consumption choices, as Lupi and Marsiglio (2021) do, for example, is common in mainstream economic literature but remains controversial (Robinson, 1997), with several credible alternatives existing (e.g. Vollset et al., 2020).

The final limitation of endogenous approaches included in this review concerns the level of integration between the demographic module and the rest of the IAM and its consequences. The integration of the demographic module depends on the amount and role of variables shared with other parts of the model. Essentially, if the vast majority of variables determining demographic dynamics, such as birth and death rates, are present exclusively inside the demographic module, then the potential for interaction between demographic and non-demographic mechanisms is minimised.

This is unfortunate, as it squanders one of the key advantages of IAMs, namely their ability to analyse the complex feedback loops connecting different aspects of the socio-economic–natural nexus. However, opening up the demographic module to external connections is not without costs. Enabling cross-module interactions greatly increases the complexity of the module, as more and more variables enter into the determination of demographic mechanisms. On the one hand, this makes it more difficult to validate the model using past data, as more and more parameters of often uncertain data quality must be taken into account. On the other hand, as feedback loops expand to include more and more non-demographic variables, it makes the nature of the mechanisms modelled unclear, as factors deemed marginal in demographic studies may assume a critical role due to idiosyncratic characteristics of the model. While a more complex structure enables more complex analyses and policy approaches to be developed, its costs in terms of clarity and validity should not be underestimated.

The above discussion demonstrates the significant heterogeneity present in demographic modelling within the context of IAMs. No obviously superior choice exists. The choice of modelling approach ultimately depends on the assumptions regarding (1) the main drivers of demographic trends; (2) the primary policy levers that affect demographic developments; and (3) the level and complexity of interactions between demographic mechanisms and the socio-economic–natural nexus. It may be argued that the decision on the demographic model structure should be based solely on the ability of the various competing modelling approaches to closely simulate data on past trends. However, most influential approaches to demographic modelling have proven able to provide similarly satisfactory fits to past data (Court & McIsaac, 2020), although the performance may differ according to the specific region and time period taken into account (Vollset et al., 2020). While a data-driven approach is essential for the determination of assumptions regarding parameters, structural questions about the future can only be settled through a *priori* theoretical choices. Of course, this is equivalent to stating that they cannot be fully settled at all. At Earth4All, we have decided to take a fully endogenous, highly coupled approach to demographic modelling. In the next section, we will illustrate the assumptions that have motivated this choice.

3. Earth4All approach to socio-demographic development

In the Earth4All model, birth rates are explicitly and causally modelled as a function of GDP per person, depicting a negative correlation between income and fertility rate. This univariate Gaussian function provides a very close fit to data on both global and regional scales (Court & McIsaac, 2020). In this context, GDP per person is to be understood as a proxy for a number of key factors, such as female education, access to contraceptives and socio-economic mobility (Vollset et al., 2020). The theoretical justification is that the ongoing demographic transition is not related exclusively to educational attainments and the availability of contraception, but more generally to the global adoption of a set of lifestyles consistent with lower fertility rates. While differentiating these effects would be preferable in the context of a pure demographic model, using a single variable that is able to effectively encompass them all is a great advantage for a complex IAM, including hundreds of other variables and parameters. Furthermore, a univariate causal model makes it easier to understand the connection between demographic trends and the main natural, economic and social dynamics depicted in the rest of the model. Finally, the approach is scalable to both global and macro-regional data. As the figures below show, this convenient solution does not sacrifice fitness to data. The effectiveness of this causal mechanism is further illustrated by the fact that even the simpler, 20-year cohort model is able to satisfactorily simulate 40 years of actual data over 10 macro-regions, as shown by Figure 2.

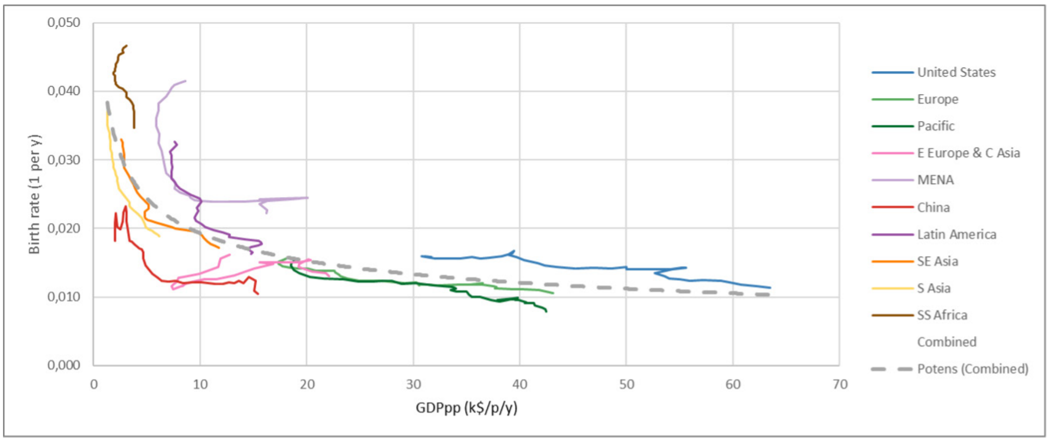


Figure 2: Relationship between birth rates and GDP per person for 10 global regions, and a global average "guideline" (dotted), estimated using 1980–2018 data.

As illustrated above, the relationship appears to be robust and consistent despite the substantial contextual differences particular to each region. The negative relationship between GDP per person and fertility rate is supported by 40 years of demographic data, providing the causal bedrock of the Earth4All model. The use of relatively simple demographic causal mechanisms, validated using best available data on both global and regional scales, has the following benefits. Firstly, it clarifies the underlying assumptions. Secondly, it makes the data produced by the demographic module relatively easy to interpret in light of the driving mechanisms. Thirdly, it facilitates the integration of additional factors in future iterations of the model. Despite their simple structure, however, both models are able to closely replicate 40 years of historical data, and to provide a reliable guide for near-future demographic developments.

The Earth4All model comes in three main versions: E4A-Global-20y, E4A-Regional-20y and E4A-Regional-5y. E4A-Global-20y is a global-level model, simulating the whole bio-socio-economic Earth system with 20-year cohorts. E4A-Regional-20y replicates the exact same global model causal structure but is run on 10 regions (see Figure 3) in parallel while keeping the 20-year cohort structure. E4A-Regional-5y is the more granular, “best-fit” model version run on 10 macro-regions with a 5-year cohort structure. The three model versions share the same overall structural, causal assumptions, and produce broadly similar results on an aggregate level. In this section, we describe the common underlying assumptions and resulting structure, together with accompanying justifications, and their differences, before illustrating their respective results in the following section.

Whether with 20- or 5-year population cohorts, we simulate cohort development over time, in order to integrate granular fertility and mortality dynamics. The model runs are primed using the latest available UN cohort data (UN, 2020). In the 20-year version, the only fertility cohort is the one spanning the 20–40 years period, while in the 5-year version, the childbearing cohorts are between 15 and 45 years old. The first specification covers circa 90% of actual births, although the percentage varies across different regions, while the second specification covers 99% of actual births, illustrating the superior precision achievable through a more granular cohort modelling. However, while the final results may be slightly different, the Earth4All answers to the demographic question are the same no matter which model specification is ultimately used.

An issue arises, however, when future scenarios are simulated. Left uncorrected, the negative relationship between GDP per person and fertility rate leads to a steadily decreasing birth rate, eventually resulting in near-zero birth rates (i.e. “human voluntary extinction by wealth before 2300”). This outcome appears improbable in the long run, especially in light of present trends within Nordic countries, in which a high and steadily increasing income per capita is accompanied by stable fertility levels (Jalovaara et al., 2019). Furthermore, the data plotted in Figure 2show that, while the relationship remains negative, its effects are significantly weakened as GDP per person increases beyond the $15K per year threshold. Therefore, the causal relationship between income per capita and fertility is corrected by adding a floor, whose value is calculated on the basis of present data. We do believe that such correction is reasonable and evidence-based; we acknowledge, however, that significant uncertainty about future development exists, and that different floors could exist for different macro-regions, depending on contextual factors outside the global scope of the model.

More significant differences between the two versions of the model exist with regard to mortality rates. The 20-year cohort version integrates a bivariate function of life expectancy predicated on income per person and climate change: the first factor increases life expectancy, while the second decreases it. Instead of simulating mortality at various life stages, all individuals in the model are expected to expire only when they fulfil their life expectancy. While unrealistic, this assumption greatly simplifies the calibration work required by regionalisation efforts, without producing significant distortion at the aggregate level of analysis. The 5-year cohort version of the model uses a univariate function of mortality rates instead, based exclusively on income per person, calculated for each cohort with significant mortality rates according to UN data, namely for infants (0–5 years old) and mature adults (35 years onwards).

The negative correlation between income and mortality rates is well approximated by a power function, which provides an excellent fit to historical data up to the 90+ years cohorts, when biological factors impose an exogenous and significant mortality rate increase. While the negative impact of climate change is not directly simulated, it is still indirectly included through its negative effects on GDP per person.

The negative correlation between income per person and mortality rate is a proxy for increased access to health care, through a combination of national and private health care systems, improved satisfaction of primary needs (such as nutrition and housing), and healthier lifestyles, with reduced workloads and increased recreational and fitness-oriented activities. The positive correlation between climate change and mortality rate included in the 20-year cohort model represents increased hazard risks from extreme climate events and health-threatening pollution levels. As with the fertility rate/GDP mechanism, the link between mortality rate and GDP per person is also visible in the data, as illustrated by Figure 3.

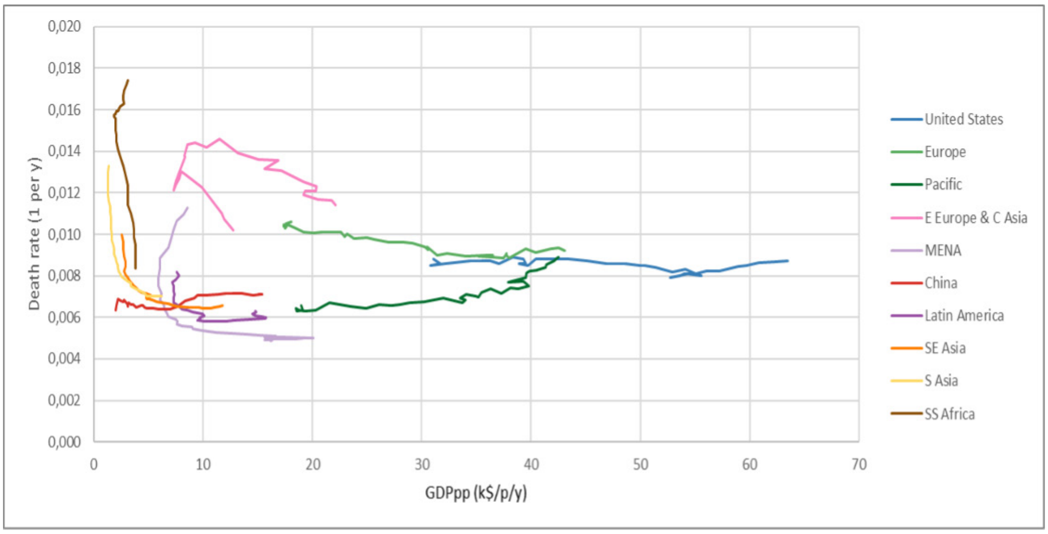
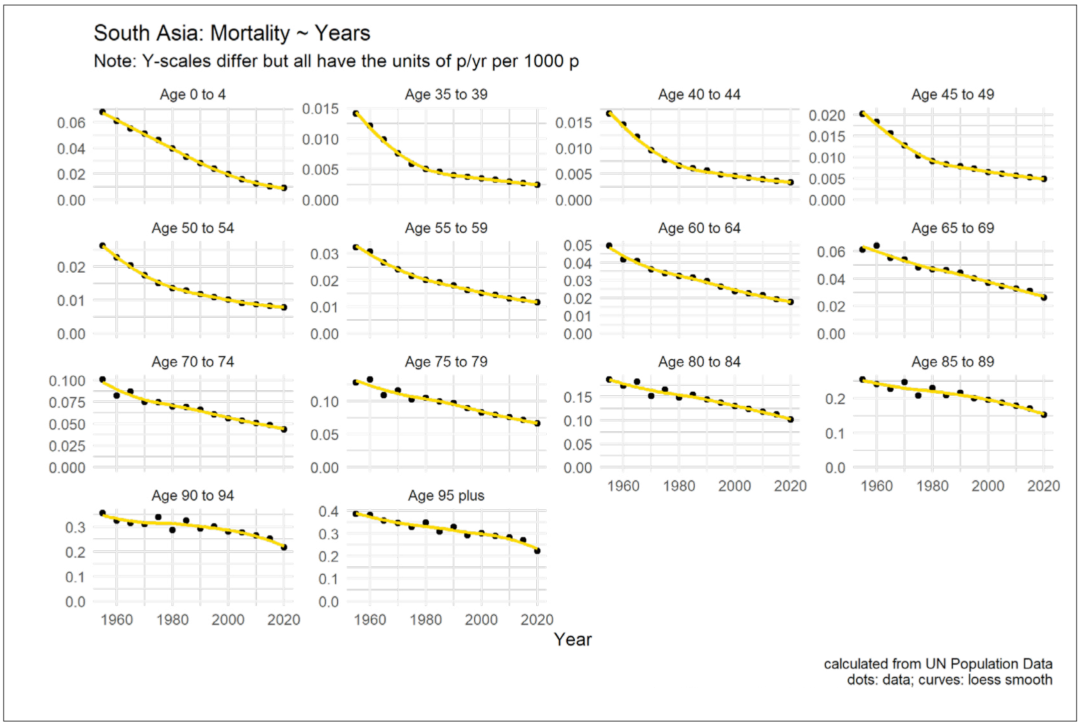


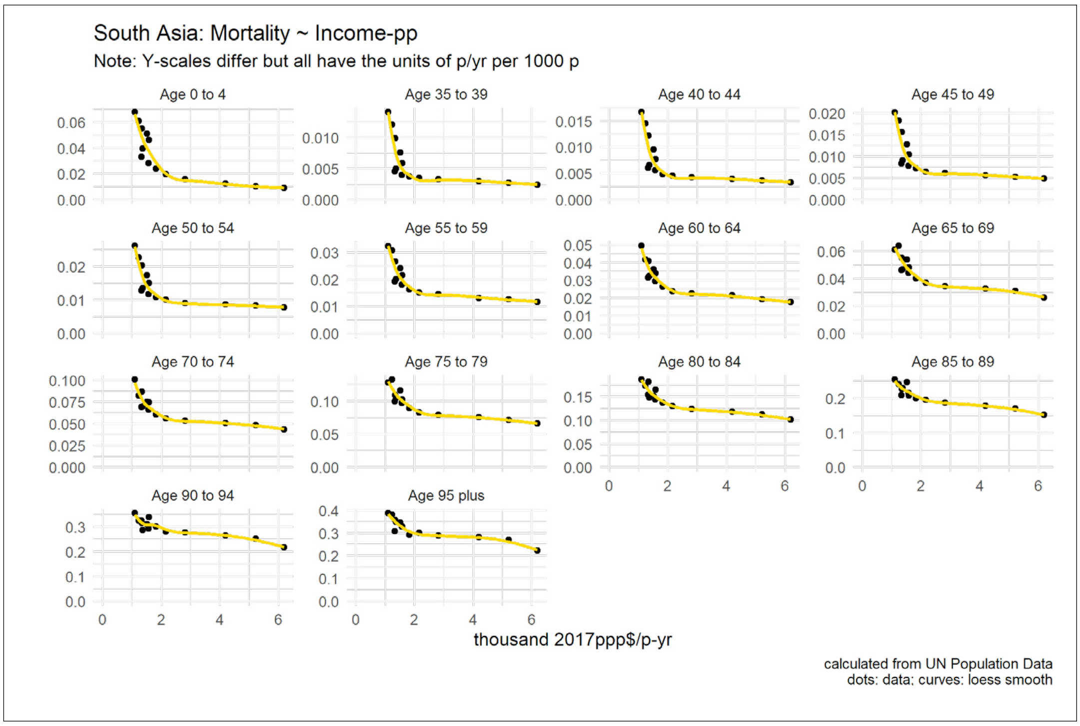
Figure 3: Relationship between death rates and GDP per person for 10 global regions.

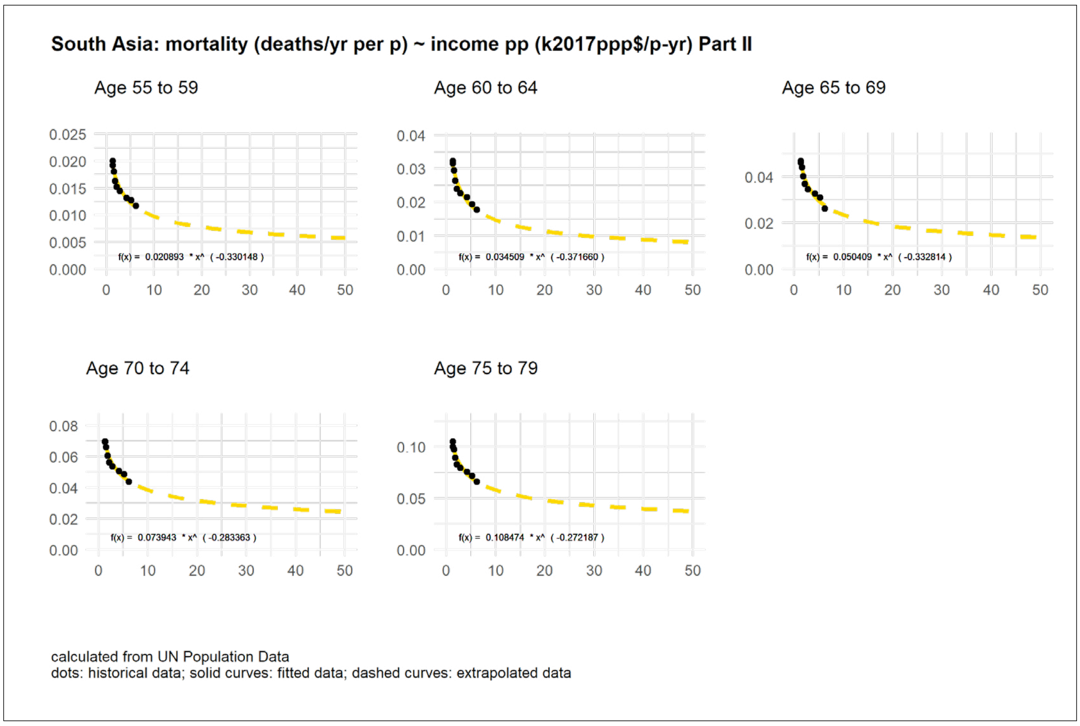
The relationship between death rates and GDP per person, while well supported from statistical analysis (Niu & Melenberg, 2014), is less evident from a cursory glance at the graphs, especially in comparison with the relationship between birth rates and GDP per person. The primary factors that must be taken into account for a clearer picture to emerge are early- and late-age mortality dynamics. In income-poor countries, infant mortality can be very high, greatly influencing mortality data. The reduction in infant mortality brought by modern medical practice is very significant, rapid and requires relatively little in the way of economic resources for the implementation of effective procedures. This goes a long way to explaining the very steep mortality rate decline associated with increased income shown in Figure 3. The second factor to take into account is that, as mentioned above, mortality rates become income-resistant above a certain age threshold, around the 85th year of life. Once life expectancy becomes very high, further increases in income cease to have a significant effect, leading to the flatter lines at the centre of Figure 3. Taken together, these two factors contribute to hide the impact of GDP per person on mortality rates, which, while statistically and practically very significant, is far from linear.

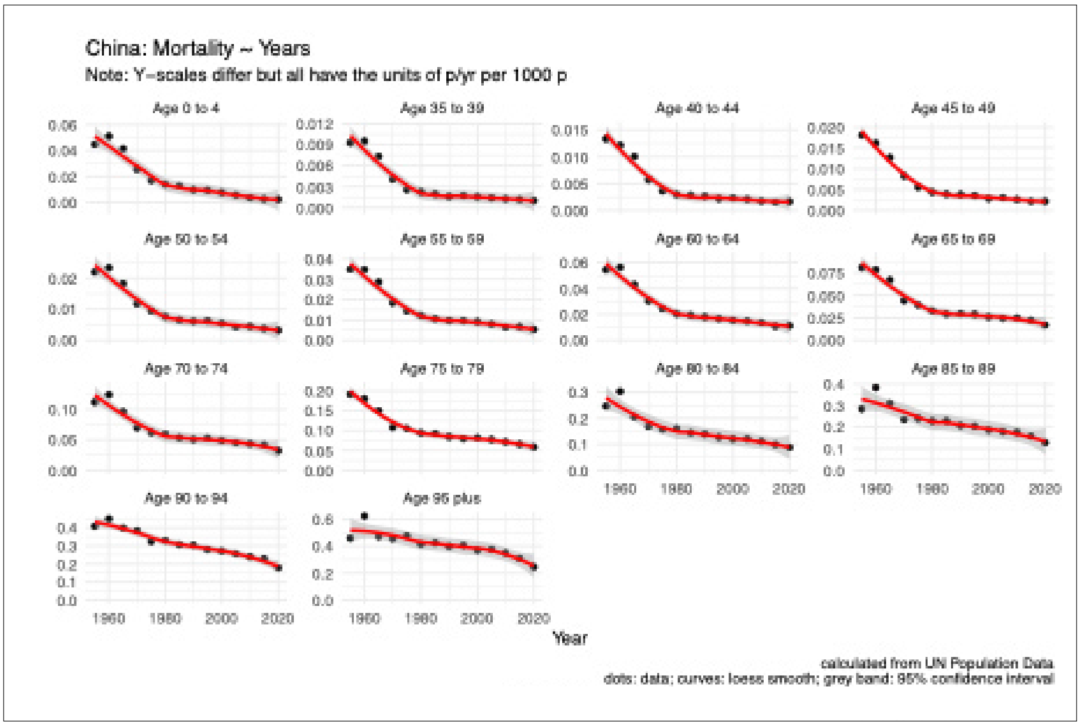
In addition to fertility and mortality rates, the 5-year cohort model also integrates a migration mechanism, absent in the 20-year cohort model. Migration is also modelled as being causally generated by the level of income per person in the target region. A better specification would take into account the income gap between migration source and target regions; however, lack of detailed migration data forces the use of a simplified endogenous model. While potentially important for the future, especially for modelling high-income regions such as Europe and North America, at present annual immigration is such a small percentage of the population that it has no significant consequences for forecasting purposes. Consequently, the mechanism remains inactive in the current simulation runs. It does enable, however, the use of the Earth4All model to simulate the potential impact of a wide variety of migration policy options.

The following figures provide an illustration of the ability of Earth4All's demographic module to effectively replicate 40 years of mortality data on a macro-regional scale using the univariate causal model:




South Asia: Mortality ~ Income-pp
Note: Y-scales differ but all have the units of p/yr per 1000 p
Age 0 to 4
Age 35 to 39
Age 40 to 44
Age 45 to 49
Age 50 to 54
Age 55 to 59
Age 60 to 64
Age 65 to 69
Age 70 to 74
Age 75 to 79
Age 80 to 84
Age 85 to 89
Age 90 to 94
Age 95 plus
thousand 2017ppp$/p-yr
calculated from UN Population Data
dots: data; curves: loess smooth


South Asia: mortality (deaths/yr per p) ~ income pp (k2017ppp$/p-yr) Part II
Age 55 to 59
f(x) = 0.020893 * x^ (-0.330148)
Age 60 to 64
f(x) = 0.034509 * x^ (-0.371660)
Age 65 to 69
f(x) = 0.050409 * x^ (-0.332814)
Age 70 to 74
f(x) = 0.073943 * x^ (-0.283363)
Age 75 to 79
f(x) = 0.108474 * x^ (-0.272187)
calculated from UN Population Data
dots: historical data; solid curves: fitted data; dashed curves: extrapolated data



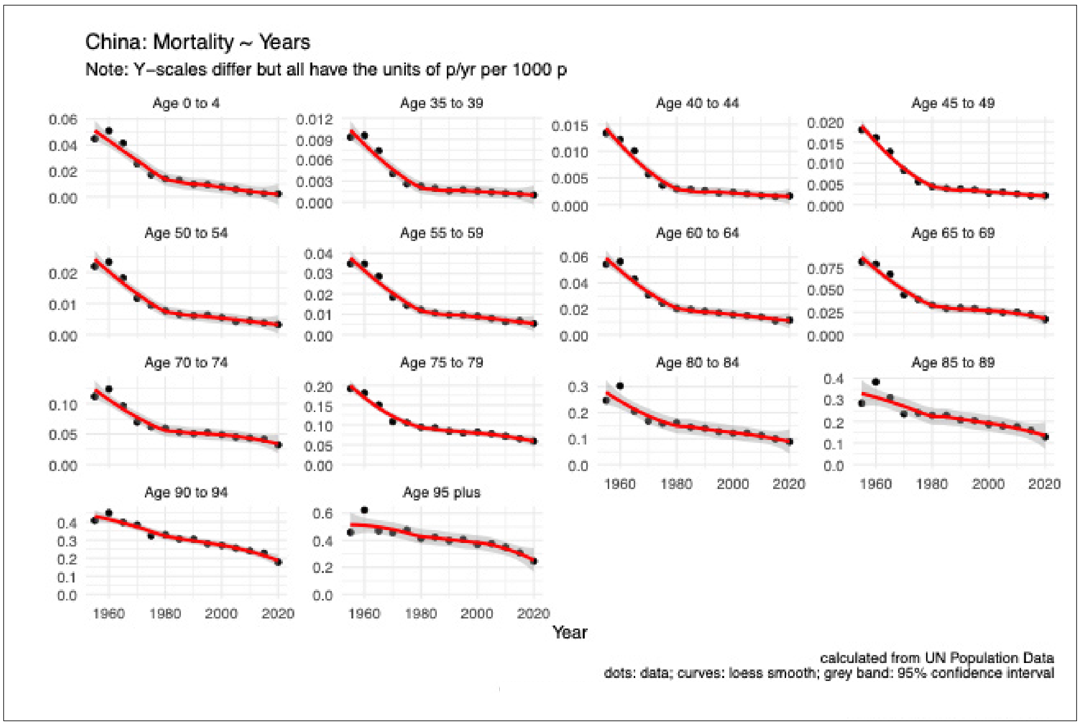


Figure 4: South Asia and China macro-regions mortality/income relationship in E4A-Regional-5y. For similar charts for both birth and death rates for all 10 macro-regions, see Appendix 2.

4. Data sources for Earth4All model

UN historical demographic data sources

E4A-Regional-5y uses 5-year cohort sizes from the UN Demographic Yearbook for 1980–2020 (UN, 2020). The E4A-Global-20y and E4A-Regional-20y models have aggregated the twenty 5-year cohorts into five 20-year cohorts (0–20, 20–40, 40–60, 60–80, 80–100).

Economic data 1980–2020

Economic data is from the Penn World Table v.10.0 (Feenstra et al., 2015), updated to June 2021, for all the world's countries from 1980–2020, further supported by the World Bank's World Development Indicators (World Bank, 2018).

World regions

The countries are then aggregated into 10 regions; the resulting division is illustrated in the following map:

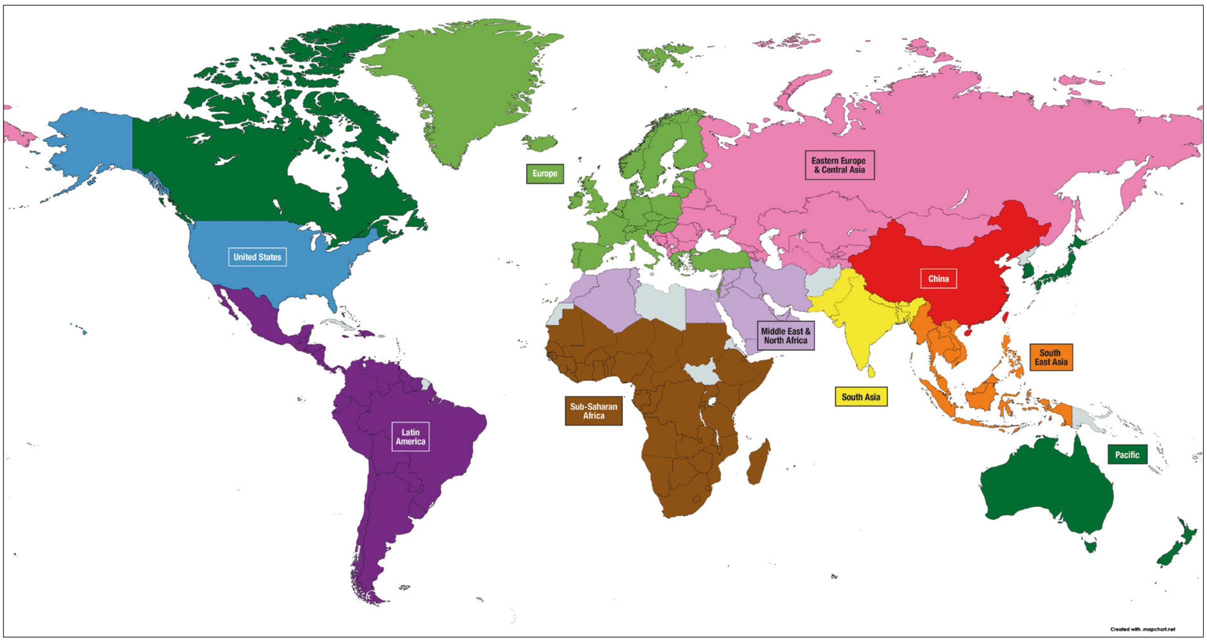


Figure 5: The 10 macro-regions used by Earth4All.

5. Results

In this section we present the two main scenarios for the demographic, social, economic and ecological development to 2100 developed by the Earth4All project: (1) Too Little Too Late and (2) The Giant Leap. We then make use of these two scenarios to provide specific answers to the GCF's research call questions.

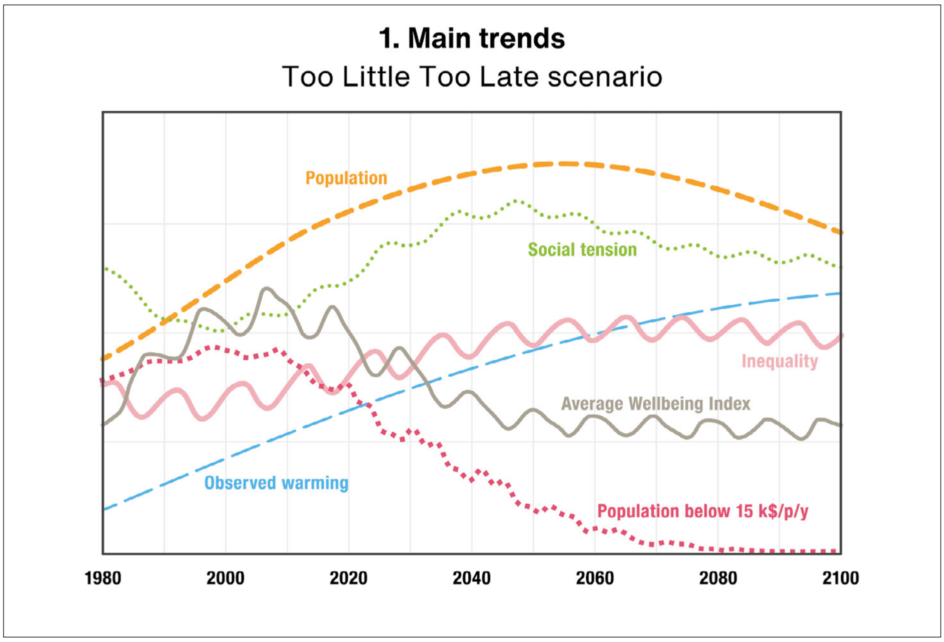
5.1. Two scenarios for global population and world development to 2100

Scenario 1: Too Little Too Late

This scenario shows the consequence of continuing world development along the same dynamics observed from 1980 to 2020. It represents "decision-making as usual". In Earth4All this is modelled by letting key trends such as birth rates, savings rates, debt ratios, tax levels, worker share of income etc. run along according to prevailing system logic in the upcoming decades.

The overall global result is a somewhat slowing global population and economic growth to 2050 and beyond, accompanied by declining labour participation rates, declining trust in government, a steady increase in inequality and a steady increase in the ecological footprint along with huge losses of wildlife. Although the scenario does not result in an overt ecological or total climate collapse, the likelihood of regional societal collapses nevertheless rises throughout the decades to 2050, as a result of deepening social divisions both internal to and between societies. The risk is particularly acute in the most vulnerable, badly governed, and ecologically vulnerable economies.

In this scenario, the global population peaks at just below 9 billion in 2046 and declines to 7.3 billion in 2100.



The Too Little Too Late (TLTL) scenario is visualised in Figure 6 with four charts that display

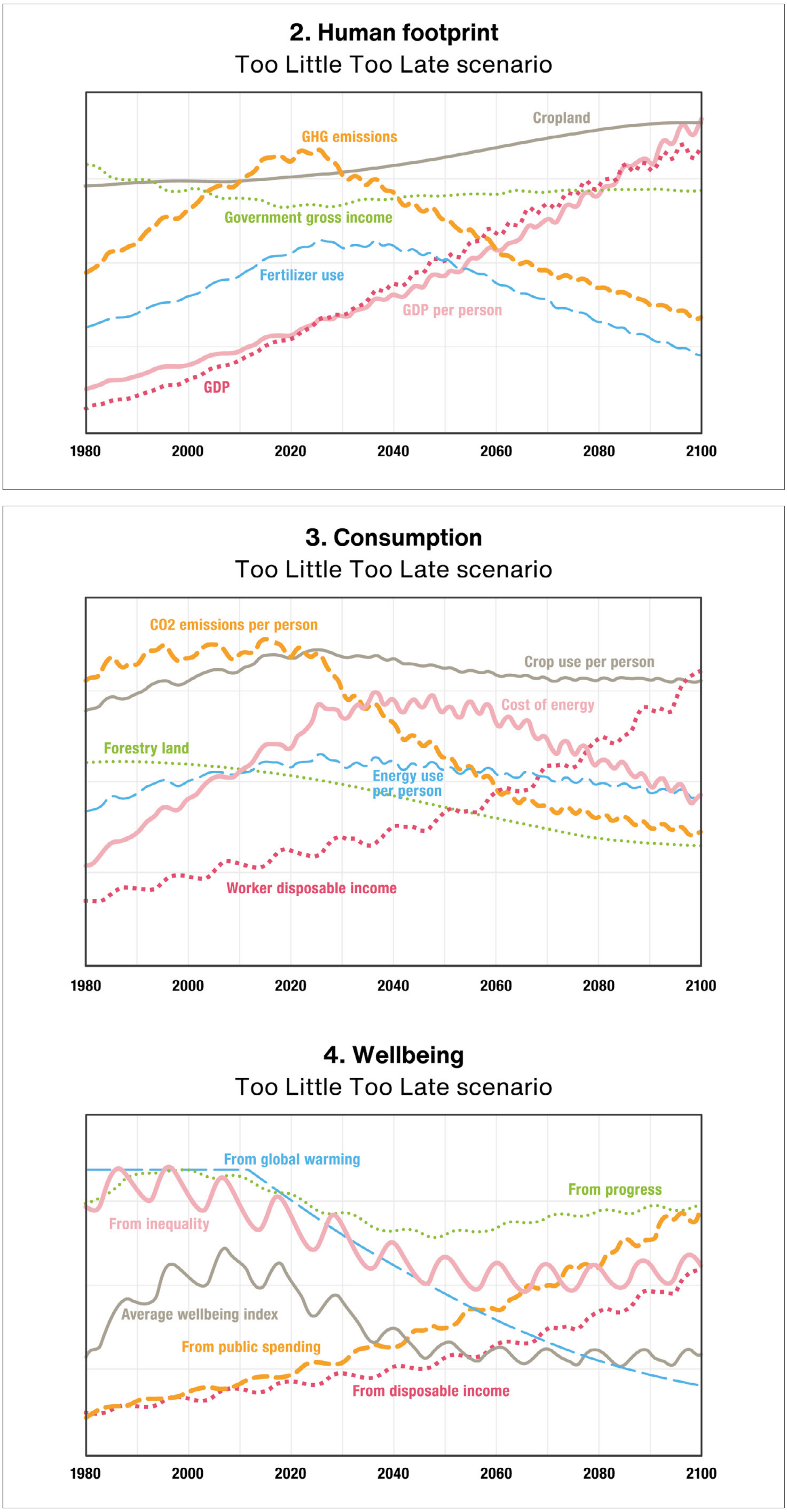


Figure 6: Key trends describing the Too Little Too Late scenario. Source: E4A-global-220501.

the main global developments in this scenario as time-series from 1980 to 2100. These curves are all relative to 1980 values and highlight the dynamics between them. Global population grows from 4.4 billion in 1980 and peaks at 8.8 billion in the 2050s before declining slowly. Income per person keeps rising from 6,000 $/year through to 42,000 $/year in 2100 as shown in chart 2. Chart 3 shows that carbon dioxide emissions and crop use per person remain high throughout the century, which drives global warming to around 2.5°C by 2100. Earth moves further beyond critical planetary boundaries. Chart 4 shows different components of wellbeing: the global Average Wellbeing Index declines through most of the century (mainly due to increasing inequality and worsening conditions in nature). "$" means US dollars (USD) at constant 2017 prices using purchasing power parity (PPP) rates. The model and data are downloadable from www.earth4all.life.

Scenario 2: Giant Leap

The Giant Leap scenario explores what it will take to rebound back strongly from the pandemic in order to eliminate poverty and provide a stable global system to make long-term economic decisions to substantially reduce the risk of Earth system shocks for the benefit of all. Governments, businesses and civil society are able to better coordinate in order to implement five extraordinary turnarounds relative to the historical trends since 1980. These five turnarounds are:

1. ending **poverty**
2. addressing gross **inequality**
3. **empowering** women
4. making our **food** system healthy for people and ecosystems
5. transitioning to clean **energy**

These extraordinary turnarounds are designed as policy and investment road maps that will work for the majority of people. They are not an attempt to create some impossible-to-reach utopia; instead, they are an essential foundation for a resilient civilisation on a planet under extraordinary pressure. The world is increasingly recognising that there are sufficient knowledge, funds and technologies in the world to implement them.

Along with renewable energy, regenerative agriculture and healthier consumption habits reduce material footprints and take a lot of pressure off natural resources. By 2050, greenhouse gas emissions are about 90% lower than they were in 2020 and are still falling. Remaining atmospheric emissions of greenhouse gases from industrial processes are increasingly removed through carbon capture and storage. As the century progresses, more carbon is captured than stored, keeping the global temperature below 2°C above pre-industrial levels. Wildlife is gradually recovering and starting to thrive once again in many places.

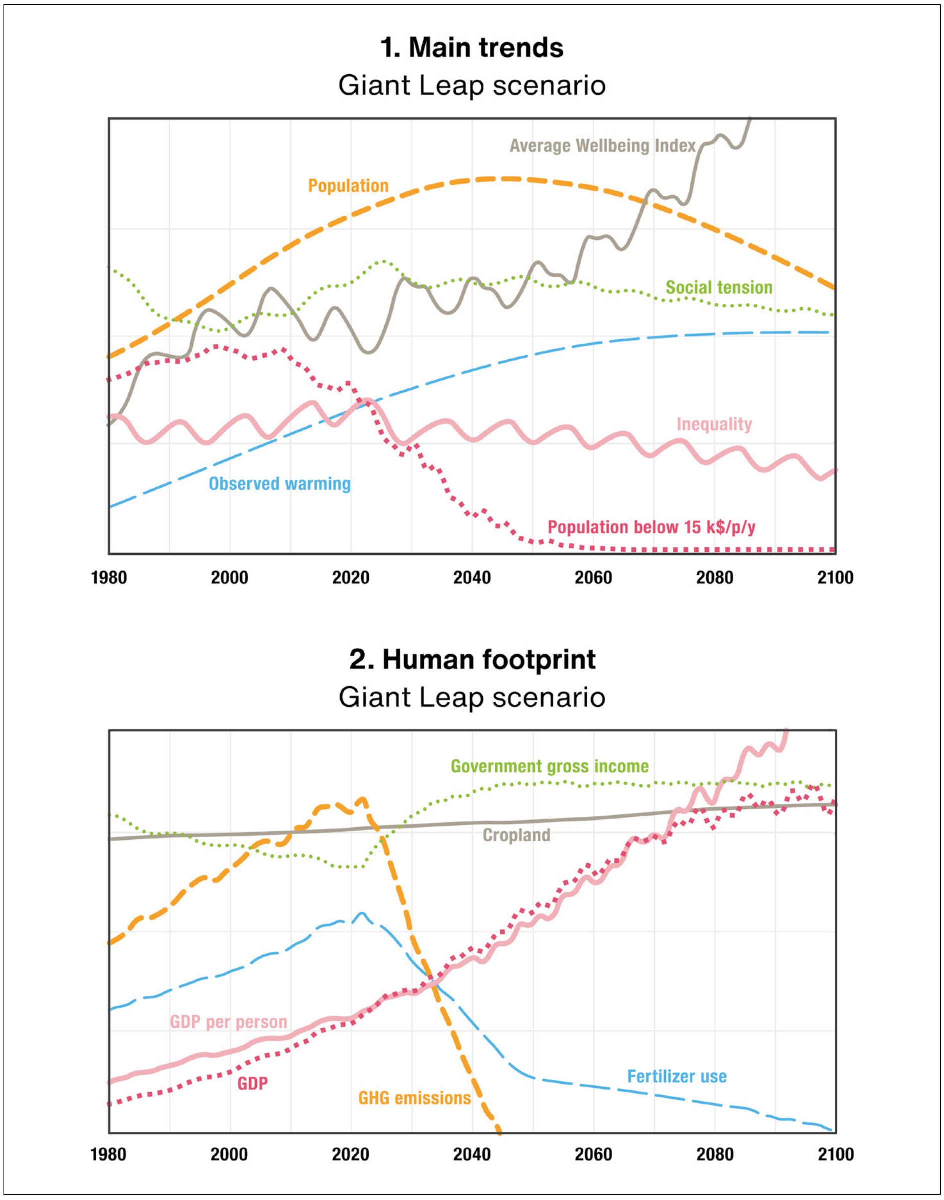
Economic inequality becomes widely acknowledged as deeply polarising and a threat to political stability and human progress. There is a broad shift in attitudes in all regions to support the principle that the richest 10% should take less than 40% of national incomes. This is based on the recognition that—whether wealthy or not—fairer societies function better than unfair societies. Different regions respond with a different mix of policies. Progressive income tax ensures the wealthiest contribute more. Wealth taxes introduced in all regions, along with the closing of tax havens, address runaway wealth inequality. An international corporation tax (agreed in 2021) provides additional income for redistribution and investment by active governments seeking common prosperity, and is adjusted and harmonised every five years. And public investment in science and research is rewarded, for example, through acknowledgment of intellectual property and stock co-ownership to the public.

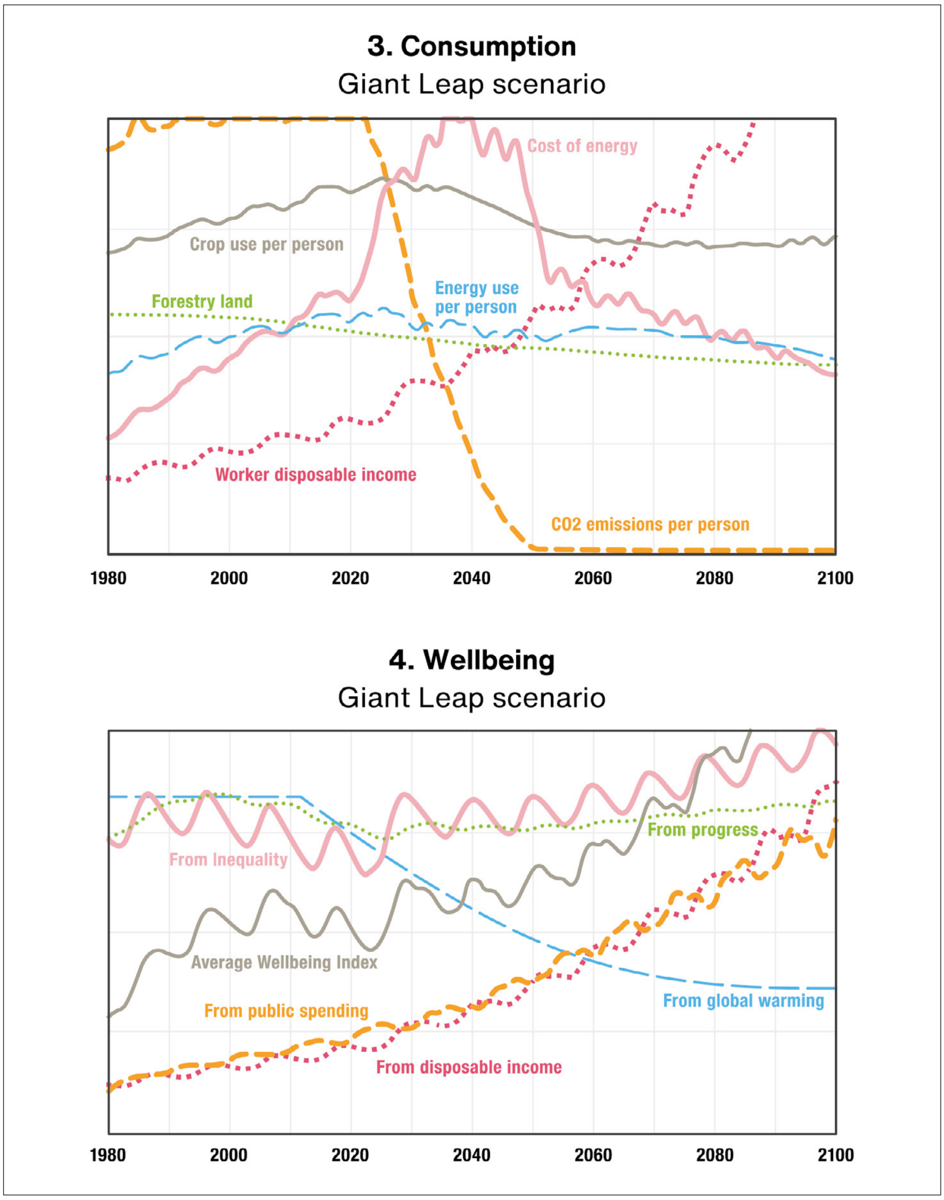
These new revenues allow governments to expand unemployment benefits (essential in a time of economic transformation) and pension schemes for all, particularly women. Gender equity improves along with a sharp increase in investment in education, jobs retraining, and health.

More countries adopt a Universal Basic Income (or similar) to provide economic security and help fight inequality, particularly as a stimulus during major shocks.

In this scenario, the global population peaks at 8.5 billion in 2040 and declines to around 6 billion in 2100.

Figure 7: Key trends describing the Giant Leap scenario.





Source: E4A-global-220501.

The Giant Leap (GL) scenario is quantified in Figure 7 as four time graphs visualising the global developments in this scenario from 1980 to 2100. The curves are all relative to 1980 and highlight the dynamics between them. The global population was 4.4 billion in 1980 and peaks at 8.5 billion in the 2050s, before population starts a slow decline to around 6 billion in 2100. Income per person (GDP per person k$/p/y) is 13% higher than in TLTL by 2050, and 21% higher in 2100. Note that the net GHG emissions per person hit zero by 2052 in chart 3. Chart 4 shows different aspects of wellbeing in the GL scenario. The global Average Wellbeing Index first declines during the early 2020s transformations, but then improves dramatically for the rest of the century, as the impacts from turnarounds kick in and improve the prospects for long-term progress. The model and all data are downloadable from www.earth4all.life.

5.2. Summary findings; our responses to the Global Challenges Foundation questions

5.2.1. Human exploitation of Earth's natural resources

GCF Q1: To what extent can humans exploit Earth's natural resources without threatening the sustainability of Earth's biosphere?

By 2020, humanity was already exploiting more than what is sustainable in global ecosystems, along multiple dimensions. This means that six out of the nine planetary boundaries have already been exceeded: climate, biodiversity, land use, nutrient flows and – recently – novel entities and green water (Persson et al., 2022; Wang-Erlandsson et al 2022; Randers et al., 2019; Steffen et al., 2015).

But if current trends in decision-making continue, as illustrated in the Too Little Too Late scenario, then the pressure against overstepped planetary boundaries will increase even further, leading to a situation characterised by ever-increasing risks of triggering irreversible declines in Earth's life-supporting systems and all its associated ecosystems.

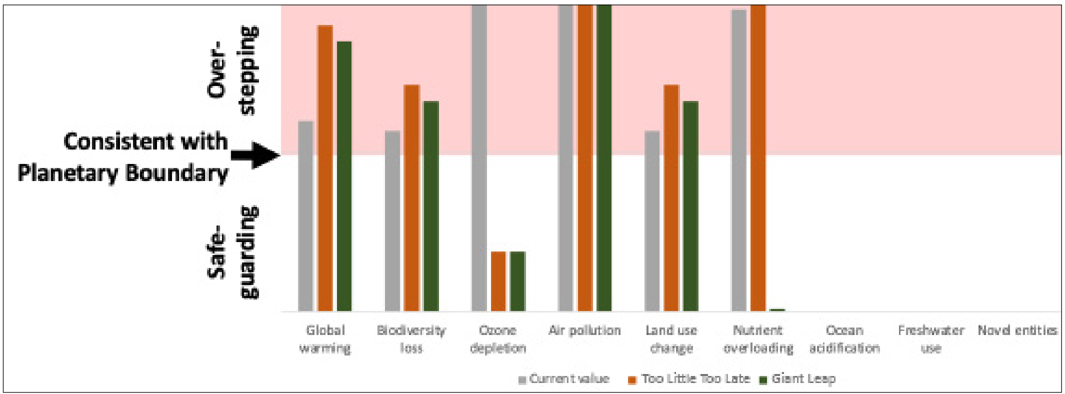


Figure 8: Status of six key planetary boundaries (PBs) in 2050: global warming, biodiversity, ozone depletion, air pollution, land use change and nutrient loading. The three others are yet not clearly quantified. The threshold values for the PBs are from Steffen et al. (2015). The planetary boundaries framework undergoes periodic updates. These results relate to PB assessments as of June 2022.

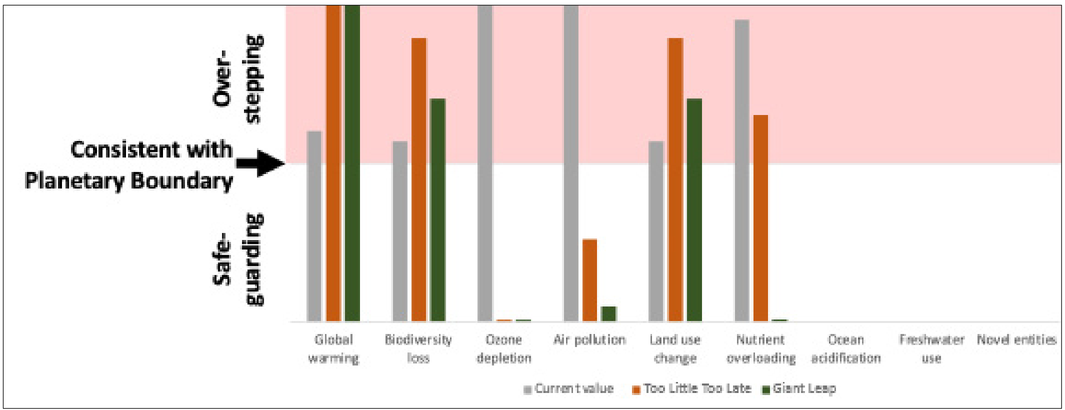


Figure 9: Status of six key planetary boundaries (PBs) in 2100: Too Little Too Late and Giant Leap scenarios. The planetary boundaries framework undergoes periodic updates. These results relate to PB assessments as of June 2022.

The Giant Leap enables more resilience for all the planetary boundaries by 2100, while moving the pressures on the ozone, air pollution and nutrient boundaries into the safeguarding zone – see Figure 9.

The policies supporting the Giant Leap scenario (see Table 3 for an overview) are sufficient to start reversing the current unsustainable human threats to ecosystems, and to continue threat mitigation into the future beyond 2100. Hence, the scenario represents a pathway towards fully returning human pressures on the planetary systems to the safe zone in civilisation's long-term view, hopefully before irreversible planetary declines are triggered. However, a recovery is most plausible only for some of the planetary boundaries, such as nutrient overloading, ozone depletion, ocean acidification and air pollution. Even in the Giant Leap scenario, although mitigation happens across the board, many of Earth's nine life-supporting systems cannot be fully returned to a safe operating space by 2050 or even 2100. The world does indeed in the Giant Leap scenario achieve the 2°C target by 2100 on global warming, but the planetary boundaries framework recommends staying below the 1.5°C target for humanity's safe operating space. The Giant Leap thus delivers on 2°C but not on 1.5°C, and therefore this boundary too is still being overstepped by the end of the century.

But if current trends in decision-making continue, as illustrated in the Too Little Too Late scenario, then the pressure against overstepped planetary boundaries will increase even further, leading to a situation characterised by ever-increasing risks for having triggered irreversible declines in Earth's life-supporting systems and all its associated ecosystems.

5.2.2. Long-term benefits of improved resource efficiency

GCF Q2: To what extent can humans increase natural resources (defined in question 1) through better management (for example circular economy practices), anticipated technological development and other changes in consumption and production, without lowering material standards of living?

Our answer to this question is given in the Giant Leap scenario. In it we explore the effects of better management of material resources: phasing out fossil fuels, applying circular economy solutions, more rapid technological development and changes in consumption and production, particularly in food and energy. All these efforts improve overall resource efficiency more rapidly than the historical trends and conventional decision-making. This scenario (see Figure 7) shows higher and rising wellbeing, a faster rise in GDP per person and a smaller and declining population in the second half of the century. Figure 10 shows the key turnarounds for achieving food and energy efficiency.

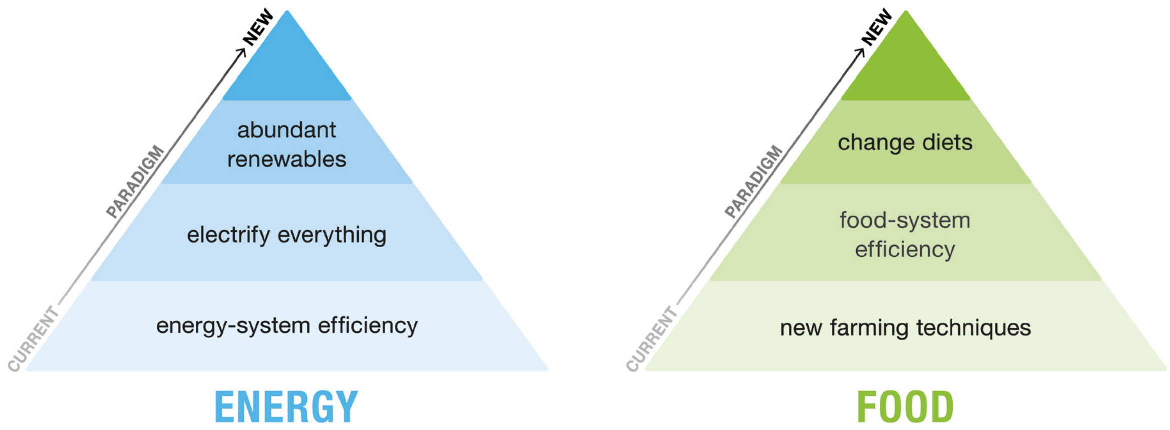


Figure 10: The food and energy turnarounds used in the Giant Leap scenario, illustrated as triangles with three key actions of rising ambition and effects.

Food and Energy Interventions / Model inputs	in Too Little Too Late	in Giant Leap
Crop waste reduction / food system efficiency	5% by 2100	20% by 2050
Regenerative agriculture (new farming techniques that yield better soils with less fertiliser use)	10% by 2100	50% by 2050
Change in diets towards non-grain-fed meat production and consumption	10% by 2100	30% by 2050
Extra yearly ROC in energy efficiency after 2022	0.2%	0.4%
Replace fossil fuels with electricity (“electrify almost everything”)	30% by 2100	80% by 2050
Renewable energy share of total energy used	90% by 2100	100% by 2050
Carbon capture use and storage, share of remaining emissions	10% by 2100	50% by 2050

Table 1: Resource efficiency improvement in the Too Little Too Late and Giant Leap scenarios. Extra ROC means Extra Rate Of Change per year above the conventional and anticipated rate of change in all sectors of the economy.

The impacts of all such improvements in resource efficiency, taken together, are wide ranging and described in the above Figures 7, 8 and 9. They also have a substantial impact on global population capacity, described in detail below. In general, according to the Earth4All simulation, immediate, ambitious policy intervention could significantly improve all the listed dimensions of resource efficiency, enabling better results to be achieved by 2050 rather than 2100.

Rapid action and results are even more important when considering the long-term nature of both demographic and physical processes, and the need for quick action highlighted by the precarious conditions of the natural planetary boundaries, as described in our answer to Q1. Furthermore, these results are achievable without reducing the population living standards; in fact, as the next answers will make clear, improved resource efficiency allows for better living standards to become achievable on a global scale.

5.2.3. Maximum number of people with minimum material consumption levels

GCF Q3: How many people could Earth's biosphere support (as defined in question 1), with increased utility value, if everybody were living on the minimum level stated in the UN's Universal Declaration of Human Rights article 25.1?

This question invites us to do some "thought experiments" which can then be quantified and run on the Earth4All model. First, it is necessary to start by giving some quantitative interpretation, or guidelines, as to what "minimum material consumption levels" means in the context of article 25.1 of the UN's Universal Declaration of Human Rights.

Article 25.1 states that: "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control."

This broad qualitative description must be translated into the rough quantitative language of Earth4All's model before a simulation can be attempted. First, each component of the standard of living must be associated with a specific model variable. Second, a suitable threshold indicating a minimum standard of living must be identified. Third, according to the question above ("if everybody were living"), we must assume an equal distribution pattern where everyone has exactly the same level of material consumption per year (at the same time as population dynamically peaks and technologies gradually improve towards higher energy efficiency and resource efficiency at the same rates of change as seen in previous decades).

After internal discussion, we decided to use the following variables and threshold values for "adequate standard of living" as shown in Table 2:

Requirement	Model variable	Threshold values	2020 data for comparision		
			US	SE-Asia	Sub-Saharan Africa
Food	Crops per person per year	400 kg	619	400	459
Energy	Electricity per person per year	6,000 kWh	12,800	1,000	400
Disposable income	Income per person per year	15,000 $	63,000	12,000	4,000
Social services	Social spending as a proportion of GDP	20%	30%	13%	15%

Table 2: Translating Article 25.1 into Earth4All terms, with United States/ Southeast Asia/Sub-Saharan Africa reference data.

Although article 25 does not mention energy directly, we have inserted it as a proxy for measuring a minimum technological standard of living conditions, affecting all other components included by the UN. Each of these four components identifies a different constraint, some more and others less binding. Two alternative approaches are then possible. On the one hand, it may be argued that, at any given time, if a single requirement is not met, then the adequate standards of living are below the minimum, no matter how much the other requirements may be exceeded. On the other hand, it may be argued that all these elements matter to individual wellbeing as a whole, and that, therefore, a degree of compensation is possible among the various components. In the following discussion, we advance the second argument, weighting each component equally, but we also provide the data required to consider the tighter constraint identified by the first argument.

Finally, the answer to Q3 depends on which scenario we expect to plausibly describe the future: TLTL or GL? If the world proceeds with "decision-making as usual" – i.e. the slow speed of food and energy transformation assumed in TLTL – then the human economy will continue to put pressure on the planetary boundaries into a high-risk zone (despite the same minimum material consumption levels for everyone). The TLTL scenario, then, describes a future where the planetary boundaries become progressively more pressured, but not so much that there is a runaway, global environmental collapse before 2100.

Clearly, however, if a grand, socio-economic transformation is achieved as in the GL scenario, then higher population numbers can be sustained at a significantly lower level of risk to planetary life-supporting systems. Thus, TLTL represents a continued substantial transgression of planetary boundaries, while GL is more in line with a future that turns towards a much lower risk to the sustainability of ecosystems.

In the following, we provide simulation results for both scenarios, with Figure 11 describing TLTL and Figure 12 describing GL:

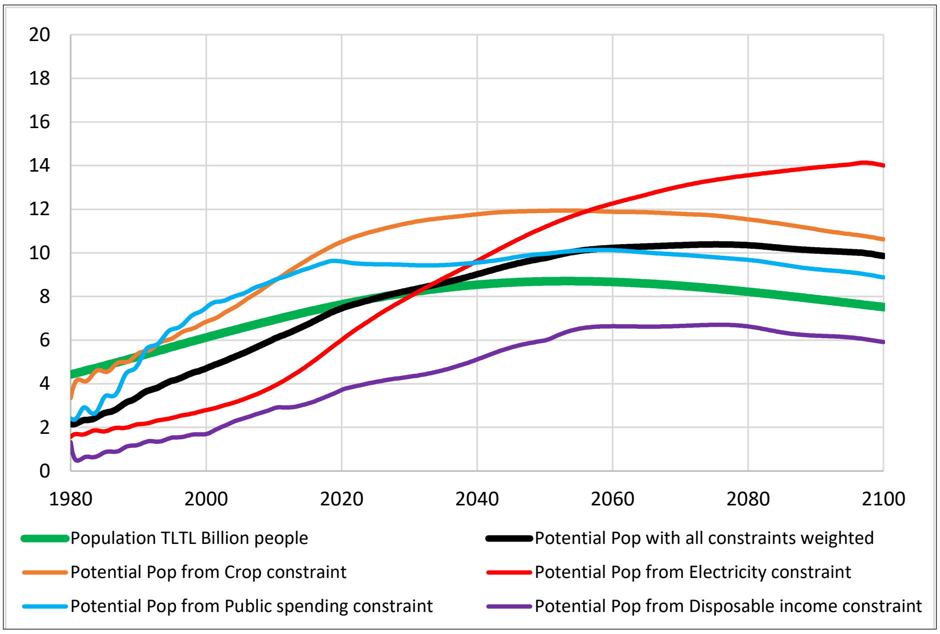


Figure 11: Maximum population at minimum living standards in the Too Little Too Late scenario: 12.5 billion in 2080.

As the figure shows, even in the TLTL scenario, projected population dynamics remain well below the weighted minimum living standards constraint from now until the end of the simulation period. This does not mean that we expect poverty to disappear, as severe inequality ensures that resources are not evenly distributed. The simulation shows, however, that the potential for everyone (up to 12.5 billion) to live above minimum living standards exists even in the less positive scenario.

[In Figure 11, the "Potential Pop from Public spending constraint" has the most powerful impact, bringing population to very low numbers by 2100. It may seem strange that using on average 20% of GDP on health and education globally is constraining population all the way down to only 3 billion in 2100. One main reason is that spending such a huge amount on health and especially education pushes birth rates way down, based on the strong historical correlation and causation between these drivers. And anything done at the entry of the demographic pipeline (2020–2050) has huge consequences later, i.e. from 2050–2100. In the real world this historical correlation may not hold into the long-term future, as women may decide to have around 2.0–2.1 children per woman when they get better health, education, pensions or similar. But in this "thought experiment" we assume that historical correlations remain unchanged in the coming decades, hence this driver is given a powerful effect and becomes a constraint on population growth.]

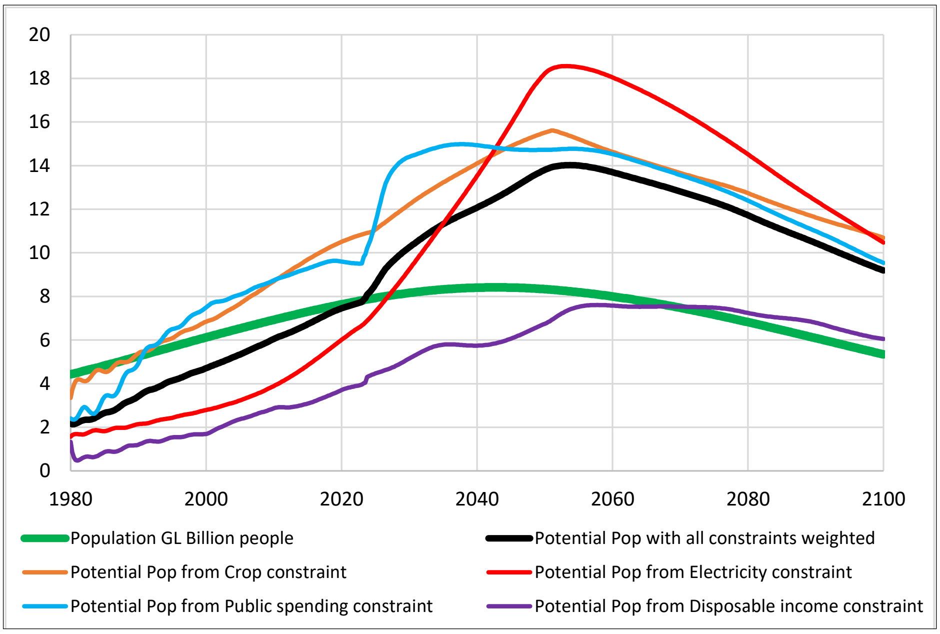


Figure 12: Maximum population at minimum living standards in the Giant Leap scenario: 14.5 billion in 2070.

In the GL scenario, characterised by significant policy and behavioural changes (such as shifts to less grain-fed red meat and electric mobility) starting at the present time, the maximum global population sustainable at minimum living standards is, unsurprisingly, higher than in TLTL. The increase can be primarily explained with the much better resource productivity brought by a combination of, in no particular order, more sustained technological progress, the implementation of circular economy processes, increased food production efficiency, the faster diffusion of renewable energy and so on.

5.2.4. Maximum number of people with higher standards of living

GCF Q4: How many people could live sustainably on Earth – within planetary boundaries and accounting for increased average life expectancy – if the average standard of living exceeded the minimum level by 10, 20 or 30% respectively?

To answer this question, it is sufficient to increase the threshold values identified in Table 2 by 10, 20 and 30% respectively, and run the corresponding simulation in both scenarios. The results are described by the following graphs:

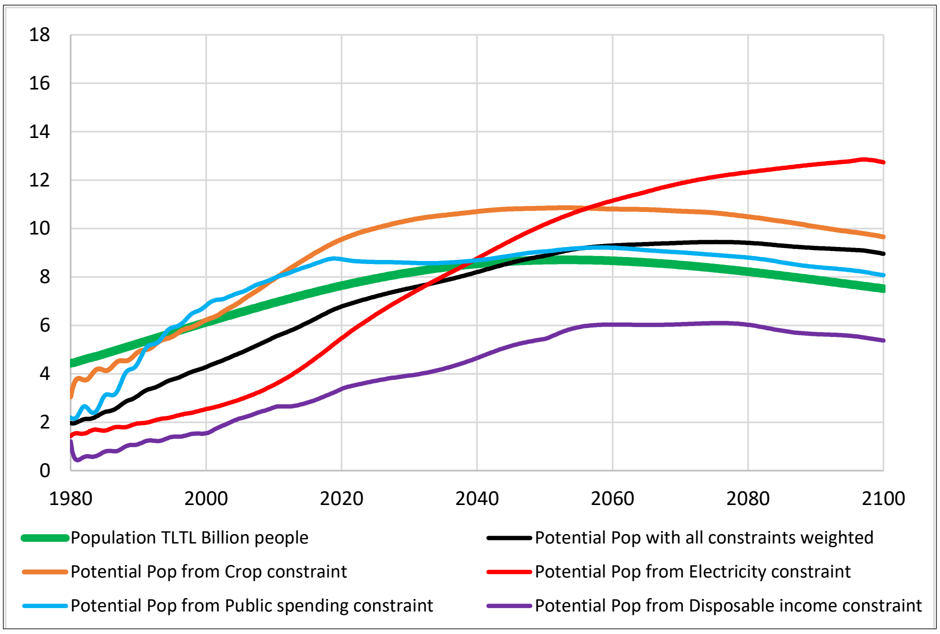


Figure 13.1: Maximum population at minimum living standards plus 10% in the Too Little Too Late scenario: 11.5 billion in 2080.

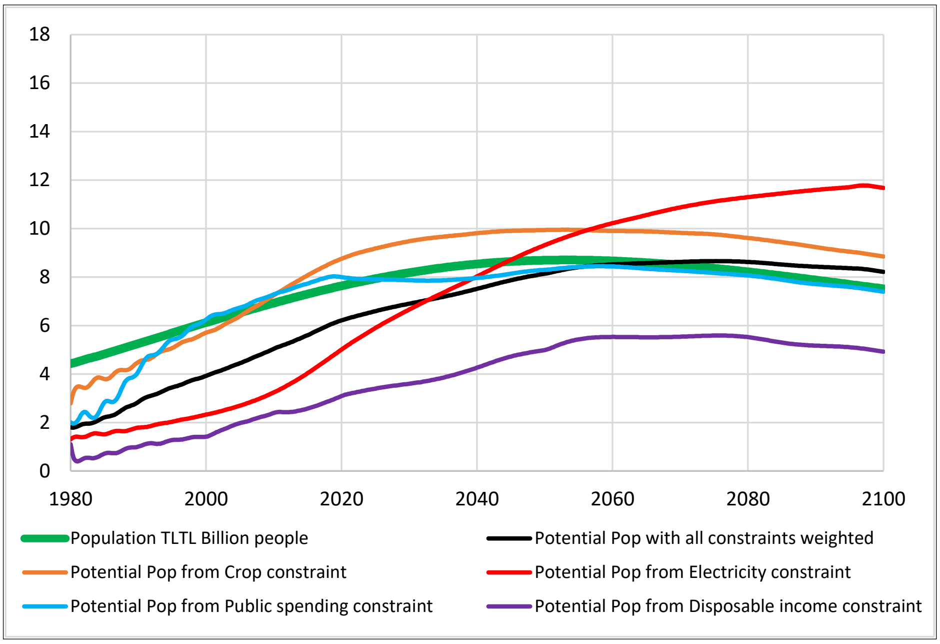


Figure 13.2: Maximum population at minimum living standards plus 20% in the Too Little Too Late scenario: 10.5 billion in 2080.

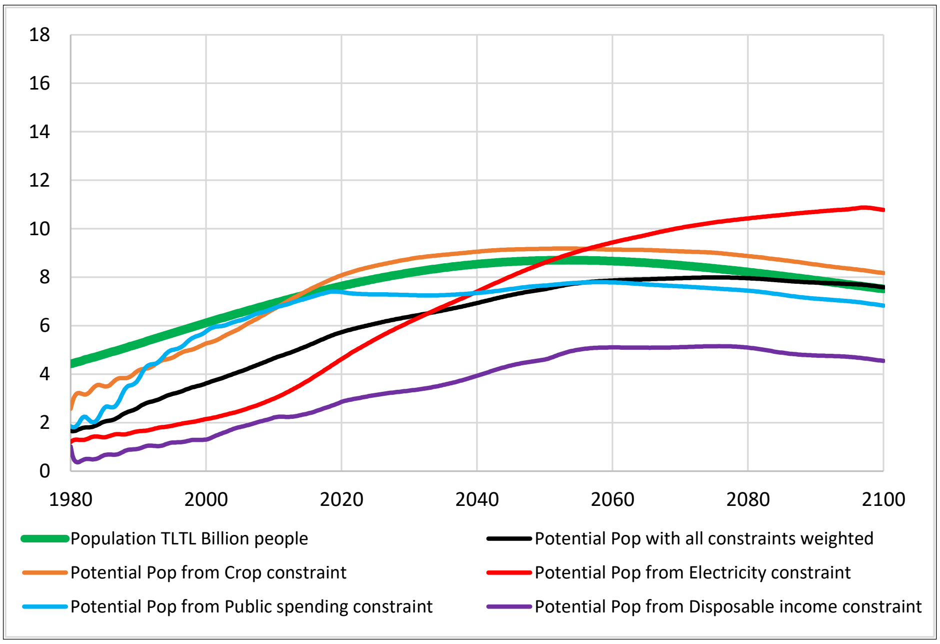


Figure 13.3: Maximum population at minimum living standards plus 30% in the Too Little Too Late scenario: 10 billion in 2080.

While numbers predictably decline across all scenarios, the main result obtained in the previous section survives: even in the TLTL scenario, it becomes possible for a population larger than today's to live in material conditions (given that everyone lives at the exact same level of material consumption) increasingly above the minimum living standards as defined by the UN and interpreted and quantified by us. By the 2030s – assuming equal distribution of resources – the global population could live in conditions surpassing the minimum UN threshold by 10%. By 2050, potentially everybody on the planet could enjoy living conditions at least 30% better than those implied by the minimum UN threshold.

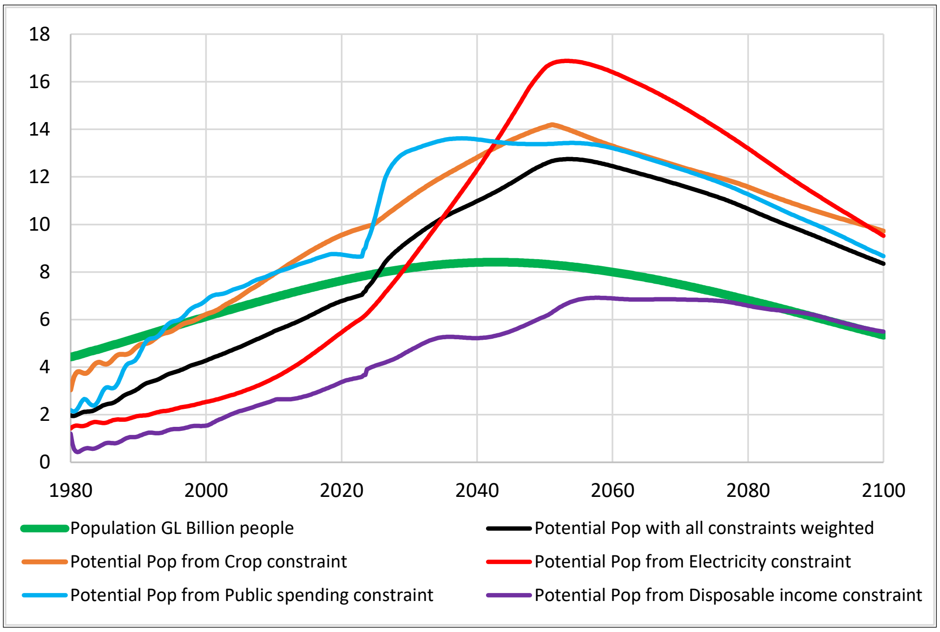


Figure 14.1: Maximum population at minimum living standards plus 10% in the Giant Leap scenario: 13 billion in 2070.

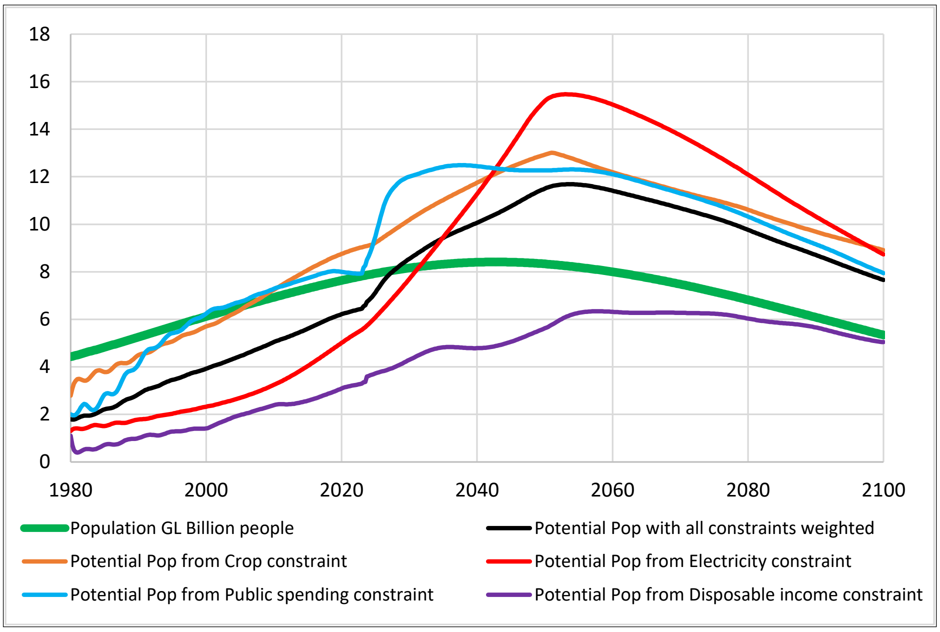


Figure 14.2: Maximum population at minimum living standards plus 20% in the Giant Leap scenario: 12 billion in 2070.

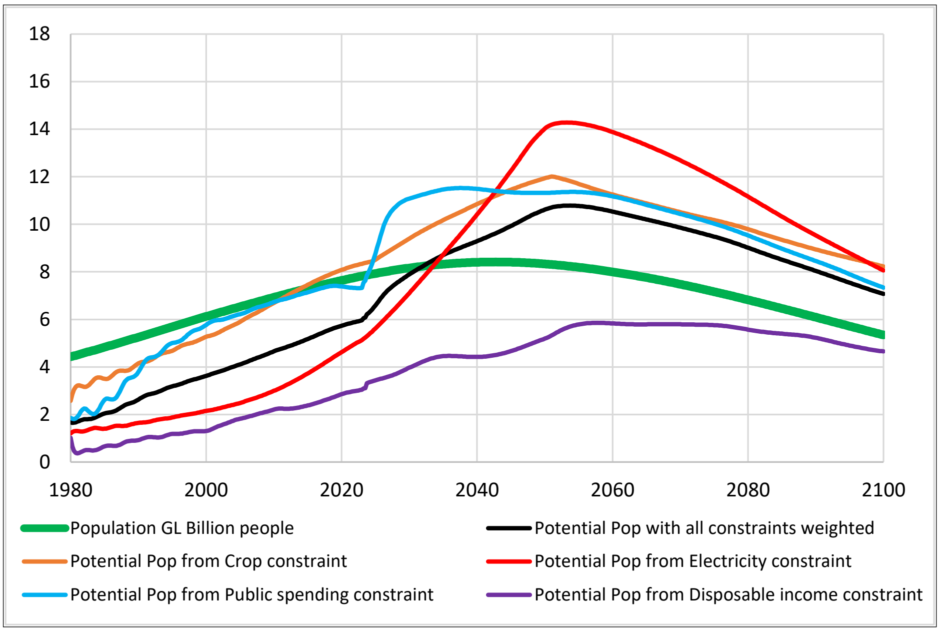


Figure 14.3: Maximum population at minimum living standards plus 30% in the Giant Leap scenario: 11 billion in 2070.

Similarly to the previous answer, we find that the GL scenario consistently provides for higher amounts of people to live at higher-than-minimum standards. More interestingly, the model simulates that such a situation can be reached much sooner, with even the highest threshold (30%) being reached by 2030. This is a powerful illustration of the great potential for meaningful, far-reaching change that sustainable policies may produce in a relatively short time: a Giant Leap is possible.

5.2.5. Measures to attain a long-term sustainable global population?

GCF Q5: If any or several of the answers to the questions above is less than the current population, the question becomes: What are the most appropriate and important measures to reach a long-term sustainable global population, according to the best available scientific evidence?

First: none of the weighted population projections in sections 5.2.3 and 5.2.4 are less than the current population (of 7.8 billion people). If one assumes low and very equally distributed material consumption per person, then there seems to be room on Earth for more people, not fewer. Nevertheless, these results point to an important recognition that we would like to discuss here.

According to our results across all simulations for both scenarios, *the primary issue is not overpopulation in comparison with available resources, but rather the current (too) high consumption levels among the world's richest quarter.* Or, put even more concisely: humanity's main problem *is distribution rather than population*.

Earth4All shows that socio-economic and natural resources are sufficient to ensure a dignified existence for the projected global population. This result, however, depends on an equal distribution of resources – something very, very far from current conditions. Therefore, we would argue that the most appropriate and important measure to reach a long-term sustainable global population is a strongly progressive taxation, targeting primarily the richest elements of the global population. The resources thus levied should be used to fund all the five turnaround policies to support the sustainability transition, which are listed in the box below.

This means reducing poverty in low-income countries, reducing inequality within all countries, and strengthening gender equality, while transforming the food and energy systems. If politically feasible, this approach of highly progressive tax would be the preferred one, as it would be beneficial from a natural, economic, demographic and social perspective.

In order to achieve a long-term stable and sustainable population, this approach of the five turnarounds could then, after population has started to decline some time after 2050, be complemented by policy instruments able to promote an increase in fertility rates to a level compatible with reaching and maintaining a long-term stable global population (i.e. 1.9–2.1 children per woman). This would require taking into account a degree of population redistribution according to relative over- and underpopulation in local situations (Luci-Greulich & Thévenon, 2013).

The model effectively simulates and extends a clearly visible trend that has proven its effectiveness and relevance on a global scale in the last decades. There are no reasons to believe this trend will disappear, or even significantly weaken, in the near future. This does not mean that new demographic trends could not emerge in the future, possibly also as a reaction to the new socio-economic conditions generated by the rapid ageing process that we foresee. The mature societies of the future (Harper, 2014) will be different from the ageing societies of today, and they may lead to yet new spontaneous developments, beyond and perhaps even despite policy interventions. After all, the great coming demographic transition whose surprising effects have been depicted above has not been the result of a global policy effort, although those have not been entirely lacking, but rather of a spontaneous process of social adaptation to the current process of development.

Table 3: Five turnarounds for a Giant Leap – with three policy recommendations for each.

Turnaround 1: Poverty

- Allow the International Monetary Fund to allocate over $1 trillion annually to low-income countries for green jobs – creating investments through so-called Special Drawing Rights.
- Cancel all debt owed by low-income countries (<$10,000 income per person).
- Protect fledgling industries in low-income countries and promote South-South trade between these countries. Improve access to renewables and health technologies by removing obstacles to technology transfer, including intellectual property constraints.

Turnaround 2: Inequality

- Increase taxes on the 10% richest in societies until they take less than 40% of national incomes. The world needs strong progressive taxation; closing international loopholes is essential to deal with destabilising inequality and luxury carbon and biosphere consumption.
- Legislate to strengthen workers' rights. In a time of deep transformation, workers need economic protection.
- Introduce Citizens Funds to give all citizens their fair share of the national income, wealth and the global commons through fee and dividend schemes.

Turnaround 3: Gender Equality

- Provide access to education for all girls and women.
- Achieve gender equality in jobs and leadership.
- Provide adequate pensions.

Turnaround 4: Food system

- Legislate to reduce food loss and waste.
- Scale up economic incentives for regenerative agriculture and sustainable intensification.
- Promote healthy diets that respect planetary boundaries.

Turnaround 5: Energy system

- Immediately phase out fossil fuels and scale up energy efficiency and renewables. Triple investments immediately to >$1 trillion per year in new renewables.
- Electrify everything.
- Invest in energy efficiency and storage at scale.

Source: Dixson-Declève et al. (2022) Earth for All: A Survival Guide for Humanity, p. 170.

6. Discussion

6.1. Earth4All projections relative to mainstream demographics

The demographic projections offered by Earth4All differ significantly from UN projections (Figure 15). This result is unsurprising, in light of the significant methodological and conceptual differences highlighted in the previous sections. A statistical approach can only extend the present into the future – it takes a causal systems model to envision something radically different: discontinuities and cycles. However, the differences between Earth4All predictions and the path forecast by influential models, such as the ones produced by the Wittgenstein Centre and Lancet, are in need of an explanation. This can be found in the different variables selected for modelling the fertility and mortality trends. Female educational attainment, the key variable of the Wittgenstein Centre model, while historically very significant, holds, in our view, limited value for future forecasting exercises. This is because the demographic impact of educational attainment is not linear: it is severely skewed. The diffusion of primary and middle school education is a game-changer; higher education, while not indifferent, is much less influential (Skirbekk & KC, 2012). Therefore, since, thankfully, relatively few women are presently entirely lacking in access to primary education (UNICEF, 2020), a univariate model built around female educational attainment will be unable to forecast rapid demographic change.

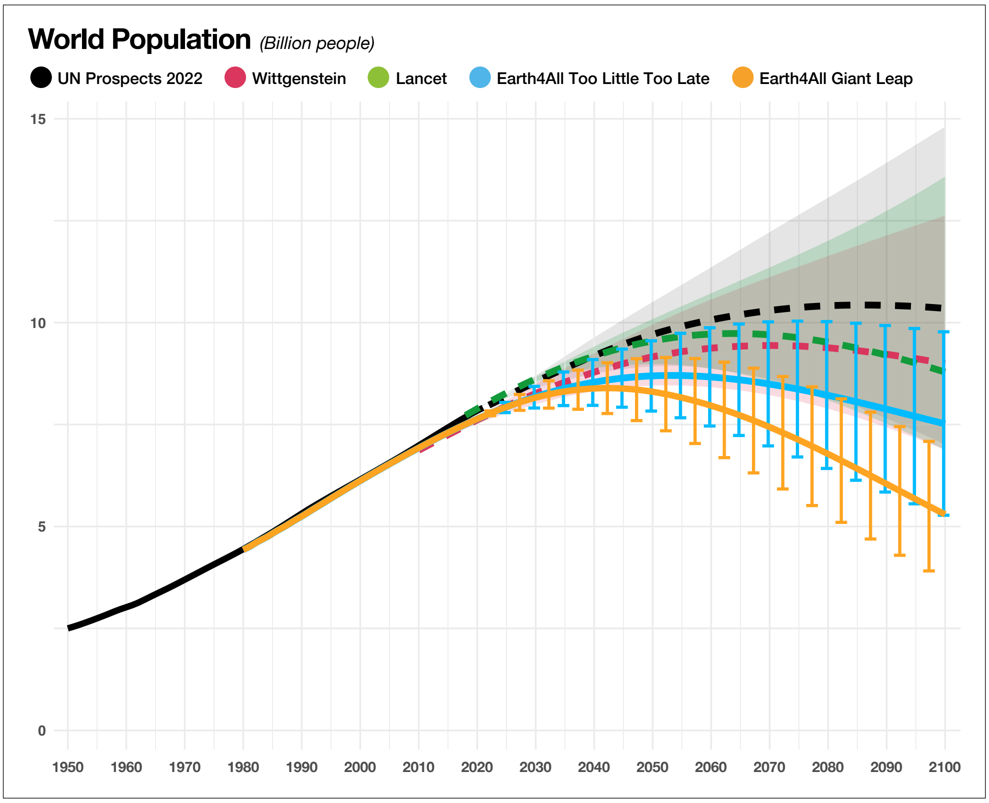


Figure 15: Comparing five population scenarios to 2100 (United Nations, Wittgenstein, Lancet, Earth4All – Too Little Too Late, Earth4All – Giant Leap).

A similar argument can be made for the Lancet model, as the addition of contraceptive access, while improving the model as a whole, does not really address the issue. Contraceptive access and use have been steadily increasing globally (Alkema et al., 2013), and, while improvements are possible and, in many areas, much needed, from a global, systemic perspective, their potential for demographic change is quite limited. It is not surprising, therefore, that the Earth4All model predicts a more rapid demographic shift in the future; after all, the other models are almost unable to. However, while Earth4All does predict a lower peak and a somewhat quicker decline, the differences with the Wittgenstein model numbers, and more especially the Lancet model numbers, are not excessive. Earth4All results should be understood as part of a current scientific trend supporting less explosive demographic trends, focusing instead on numbers compatible with the low UN scenarios.

The first key result achieved by Earth4All is that population growth is predicted to not be explosive, even in the TLTL scenario. Population is predicted to reach a maximum of 9 billion in circa 2050, and to slowly decline afterwards. Overpopulation, although locally and transitionally relevant, especially in light of possible carrying capacity degradation provoked by climate change, does not appear to be the main demographic issue of our shared future. Rather, a major issue, soon to affect many high-income countries, but soon to achieve a global dimension, will be a significant imbalance between elderly and working-age population, with all its attending issues. Health care and social support will have to be arranged and funded by a steadily declining taxpayer base, making concerted efforts towards both technological innovation and socio-economic restructuring necessary to achieve and maintain social sustainability. But the challenge will be somewhat reduced by the accompanying reduction in the fraction of young people in need of upbringing and education. Therefore, rather than a pure expansion, a restructuring of our welfare systems is what appears to be most needed, accompanied by a development of our capacity to provide care for a growing percentage of our total population.

This is a symptom of a more general issue. Demographic growth is commonly understood to be a primary driver of climate change, through its role of emissions multiplier. It is argued that planetary boundaries identify a specific carrying capacity for human population, and that beyond such limits achieving sustainable development trajectories becomes exceedingly challenging. This is often expressed through the so-called IPAT and Kaya identities, which decompose environmental impact of an economy in multiplicative components encompassing population, income, technology, and pollution intensity (Ehrlich & Holdren, 1971; Kaya & Yokobori, 1997). Such models, however, implicitly assume that the rate of technological advancement and productivity increase (necessary to reduce the emissions for aggregate income ratio) are exogenously given, and therefore unaffected by the other components of the model. These models capture the demand effect of population, expressing the fact that more consumers demand more resources, but ignore the supply effects of labour and resource inputs on production. Endogenous growth theory argues instead that the world economy's production frontier is pushed by innovation and that labour is the central input in the innovation process (Kremer, 1993; Romer, 1990). While skilled labour is the primary driver of technological development, having more labour in general allows society to educate more people, to allocate more people and time to research purposes, and to multiply the learning effects of research as the scale of production increases. It also raises the probability that successful Schumpeterian innovators, bringing novel ideas to the market through radical innovation, will enter the stage (Braunerhjelm et al., 2010).

According to endogenous growth theory, lower population growth may in principle imply a lower rate of technological development and productivity growth (Bretschger, 2017, 2021), through an absolute reduction in the numbers of the active skilled workforce. While actual innovation processes are certainly more complex, as most research activities take place at the forefront of the production frontier (Legler & Krawczyk, 2006), and therefore in high-income countries, where advanced economic activities are more common (Schmitz & Strambach, 2009), the workforce decline of the near future might have a negative effect on our technological advancement capabilities – a particularly problematic issue in light of the increased demand for technological solutions arising from both the natural and social domains. Therefore, these social challenges require socio-economic transformations to be met: neither "rosier" demographic projections nor productivity increases may be sufficient to provide effective solutions to these problems, whose beginnings can be felt already today. The present process of prolonging work participation further by delaying retirement may ameliorate the issue, but it should be supported by the development of new models of work participation better suited to the particular skills profile of the older section of the workforce. Again, a qualitative restructure of our employment dynamics is required to meet the challenges raised by the incoming quantitative decline of the available labour pool, particularly in the second half of the century.

These and similar considerations are brought to light by the original demographic causal structure adopted by Earth4All. A comparison with the augmented DICE model (Lupi & Marsiglio, 2021) and the Lancet approach (Vollset et al., 2020) can illustrate the issue. If the "fertility as consumption choice" approach is taken, then demographic policies must be focused on the only parameter that could be directly influenced, namely the cost of raising children, which, barring policy intervention, is assumed to be linear in capital (Barro & Sala-i-Martin, 2004). If, instead, the Lancet approach is favoured, then the key variables to be taken into account by policymakers become education attainment and contraceptive supply. Quite aside from the relative impact assigned to the specific variable, the choice of how many and which factors are key for the determination of demographic mechanisms is far from being just a methodological choice, especially when considering the clear policymaking assistance vocation of IAMs. By focusing on GDP per capita, Earth4All highlights the complex interplay existing between demographic, natural and socio-economic trends, providing better support for scenario analysis to support much-needed policy development.

It might be argued, however, that by forecasting a lower demographic trend, especially in relationship to the UN "mid-range" estimates, Earth4All minimises the demographic aspect of the ongoing climate change crisis. This is far from being the case. First of all, Earth4All is the first model to integrate a direct, negative effect from climate change to life expectancy, thus enabling the simulation of the deadly impacts of climate change, with its accompanying loss of human life. While the numbers of expected direct casualties are not high enough to affect a global trend that is measured in billions, they are more than enough to be considered a global tragedy, requiring a global response (Nolt, 2015). Secondly, by integrating a number of loss functions related to climate change, and by coupling demographic developments with GDP-per-capita trends, Earth4All is able to simulate the indirect demographic effects of climate change, which are an order of magnitude more significant than those highlighted by direct casualties. Therefore, far from minimising the issue, we can say that Earth4All's model represents a significant advance in our ability to analyse, understand and prepare for the incoming global changes in a way that can protect and benefit everyone.

6.2. Highlighting the long-term impacts of near-term actions on population

While the significant differences between the long-term demographic projections of Earth4All compared with other influential models are bound to draw attention, there are two other important results that should be highlighted. The first is that the differences between Earth4All projections and those forecasted by the Lancet model only begin after 2050; until that time, the projected trajectories are very similar across all models. This is due to the significant inertia dominating demographic trends, with past decisions exerting strong influence decades into the future.

This brings us to the second result: the significant demographic impact that farsighted and comprehensive policy change can make. As highlighted by the differences between the GL and TLTL scenarios, the lower population trajectory simulated by Earth4All is not so much a result of methodological differences or different assumptions, but rather the ability of the model to effectively portray the wide-ranging consequences of sustainable policy. Focusing on the demographic side highlights the long-term nature of sustainability choices, confirming the need to act as soon as possible in order to impact the trajectories of humanity's long-term future.

The main differences are determined causally in the actions taken in the 2020–2040 period, which then enter the population "pipeline" where it takes a generation or two until the large differences become really visible. Simply put: how many children a girl born today will have in the 2040s and 2050s is highly influenced by the level of education, health care, contraception, jobs, economic security and empowerment she gets access to from now and into the first two decades. We also found that a higher granulation on the cohorts (from E4A-Global with four 20-year cohorts, to 20 five-year cohorts across 10 regions) actually projects somewhat lower, not higher, global population numbers by 2100 (see Appendix 1 for detailed charts).

6.3. Population vs. planetary boundaries: limitations to Earth4All modelling

Attentive readers may have noticed that we do not present a scenario where all planetary boundaries are returned back to the safe operating space, i.e. in which current and future economic development does not at all "threaten the sustainability of ecosystems". This is because Earth4All does not feature hard limits to growth beyond planetary boundaries. There are no immediate and strong feedbacks from the natural world stopping the growth of the socio-economic systems (in terms of births, energy use, crop production or capital investments) from transgressing the boundaries: there is neither a "global police" nor a Gaia spirit to put an immediate stop to resource overuse. Neither have we included a third, ecotopia-scenario where humanity and Earth's systems live in perfect harmony (i.e. mid-term Holocene conditions) at the end of the century.

Rather, our model simulations in order to answer the GCF questions raise a number of interesting philosophical and ethical issues: What does it mean to return fully within planetary boundaries? When are planetary boundaries transgressed? One way is to think of these as "long fuse – big bang" problems. Just like drinking alcohol. You can drink a shot of vodka with every meal and enjoy it for a long time. Eventually, however, you will die early and possibly suddenly of cirrhosis of the liver. We know about this from numerous "experiments", most of them natural. But we do not know when the planet will die from our transgressions, as we're currently conducting the first large-scale human "experiment" on the planet's health. It seems likely that, within the TLTL scenario, we are taking mighty steps towards its "death" – its tipping into irreversible declines of life-supporting systems to human civilisation's detriment. We simply do not know exactly how resilient the planet is to overstepping the boundaries, which is why the planetary boundaries framework speaks of levels of risk, from safe to high-risk zones. There is no clear cut-off point where the Earth falls off a cliff at a certain date in the future. These are dynamic, long-term, gradual processes, and how one judges the status depends on time frames, risk-levels, human values, politics and a number of supporting assumptions that cannot be considered definitive at the moment, as our knowledge of these subjects is quickly progressing.

Therefore, some of the main ethical–political issues raised are:

- Who takes the decision on what is a tolerable level of planetary risk?
- By when should the economy's pressure on the planetary boundaries be back within safe zones? In 1, 5, 20, 80 or 120 years?
- By whom? What world countries and regions are to take the brunt of the cuts? How much should the rich give up, and by when, in order to raise those with a low income up to minimum/average/adequate standards of living while reducing their own material consumption?
- Where in the economic system should the interventions focus first? Should the energy, finance, health-care or agri-food sector go first or do the most? For instance, cutting the use of fertilisers would increase land use in order to satisfy food demand, meaning more forests would be cut, unless there is a simultaneous ban on eating grain-fed red meat or everyone changes eating habits voluntarily. Who will ensure that? How should taxation be set up to cut luxury material consumption, by how much and by whom? Similarly, how should energy sector cuts on oil consumption and production be allocated, and by when?
- Even if a transformation is technologically feasible, is a rapid, absolute decoupling of material footprint from GDP and population growth politically possible?
- If we try to further reduce population in order to reduce future material use, who decides how many children women can have (i.e. the "desired number of children per woman") and which instruments are used to reach this target?

Obviously, resolving these questions goes beyond the scope of a report on future population dynamics. Yet that is why we made *scenarios* – which are possible, plausible and holistic stories about the future. The Giant Leap is one such answer attempting to balance all these issues in order to generate a systemic, integrated answer to the GCF's research call questions, based on historical trends but assuming strong actions along the five turnarounds in the coming decades.

We fully acknowledge that other scenarios can (and should) be made, based on other assumptions and other types of policy actions. These scenarios would show different demographic, socio-economic and natural outcomes for the planet. More research in this direction is certainly needed. What we aimed to achieve with our scenarios is to illustrate that (1) demographic, socio-economic and natural change is possible, and (2) its magnitude and ultimate impact will depend primarily on the actions we are going to take in this decade.

7. Conclusion

In conclusion, these are our summary answers to the five questions raised by the Global Challenges Foundation:

1. **To what extent can humans exploit Earth's natural resources without threatening the sustainability of Earth's biosphere?**

Six out of the nine planetary boundaries have already been exceeded: climate, biodiversity, land use, nitrogen and – as recently published (2022) – novel entities and green water. While ambitious policy interventions (Giant Leap) can ensure a gradual and substantial improvement of the high-risk situation over the century relative to decision-making as usual (Too Little Too Late), there is simply not enough data at present to ascertain exactly the status of the ecosystems' stability. They may already be impaired, although the extent of damage is yet to be quantified.

2. **To what extent can humans increase natural resources (defined in question 1) through better management (for example circular economy practices), anticipated technological development and other changes in consumption and production, without lowering material standards of living?**

Earth4All shows that ambitious and feasible policy efforts implemented today (the Giant Leap scenario) would result in significant increases in resource efficiency particularly in agricultural and energy terms, with more ambitious targets being reached at least 50 years in advance when compared with the "business as usual" scenario. This increased resource efficiency would not reduce our material standards of living; in fact, it would enable better living conditions for the global population to be achievable sooner.

3. **How many people could Earth's biosphere support (as defined in question 1), with increased utility value, if everybody were living on the minimum level stated in the UN's Universal Declaration of Human Rights article 25.1?**

According to Earth4All's demographic projections, the entire current population could achieve living conditions at least comparable with the minimum level identified by the UN by 2030, even without significant changes in ongoing developmental trends, *provided there is an equal distribution* of resources.

4. **How many people could live sustainably on Earth – within planetary boundaries and accounting for increased average life expectancy – if the average standard of living exceeded the minimum level by 10, 20 or 30% respectively?**

According to Earth4All's demographic projections, the entire population could achieve living conditions exceeding the minimum level identified by the UN by 10, 20 and 30% respectively by 2030, 2040 and 2050, even without significant changes in current developmental trends, *provided there is an equal distribution* of resources.

5. **If any or several of the answers to the questions above is less than the current population, the question becomes: What are the most appropriate and important measures to reach a long-term sustainable global population, according to the best available scientific evidence?**

An ambitious programme of policy-driven change (Giant Leap), which we describe with the five turnarounds, can be accomplished through economic instruments promoting a significant redistribution of resources within and between all countries. This can stabilise the population to around 6 billion people at a much higher level of wellbeing than today.

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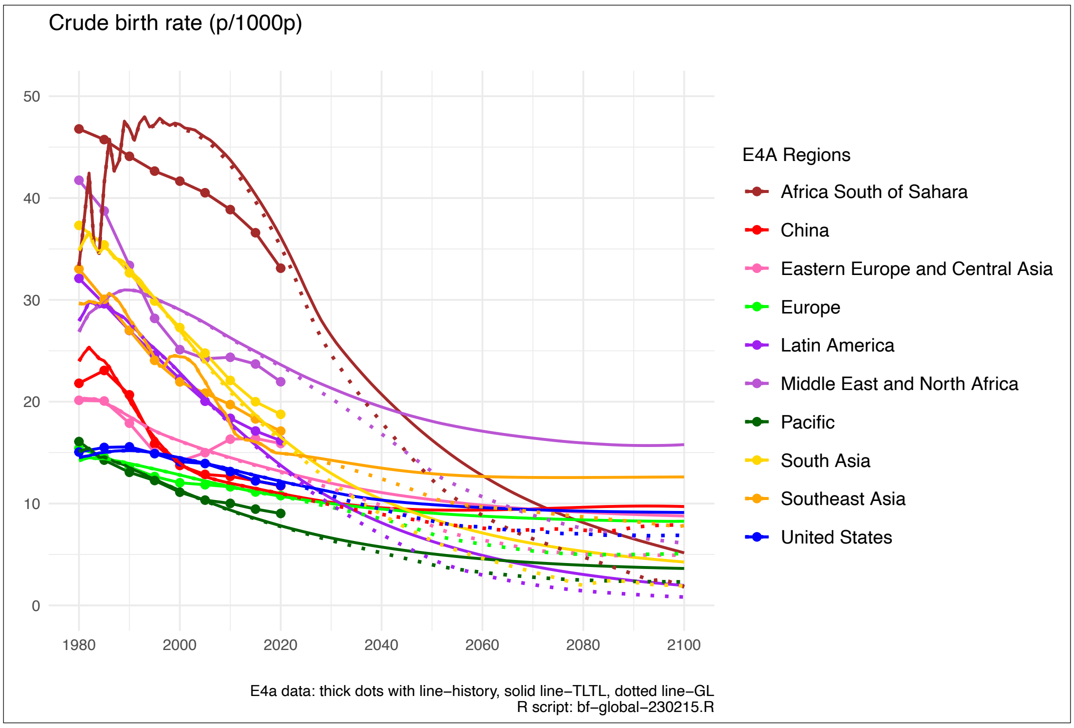
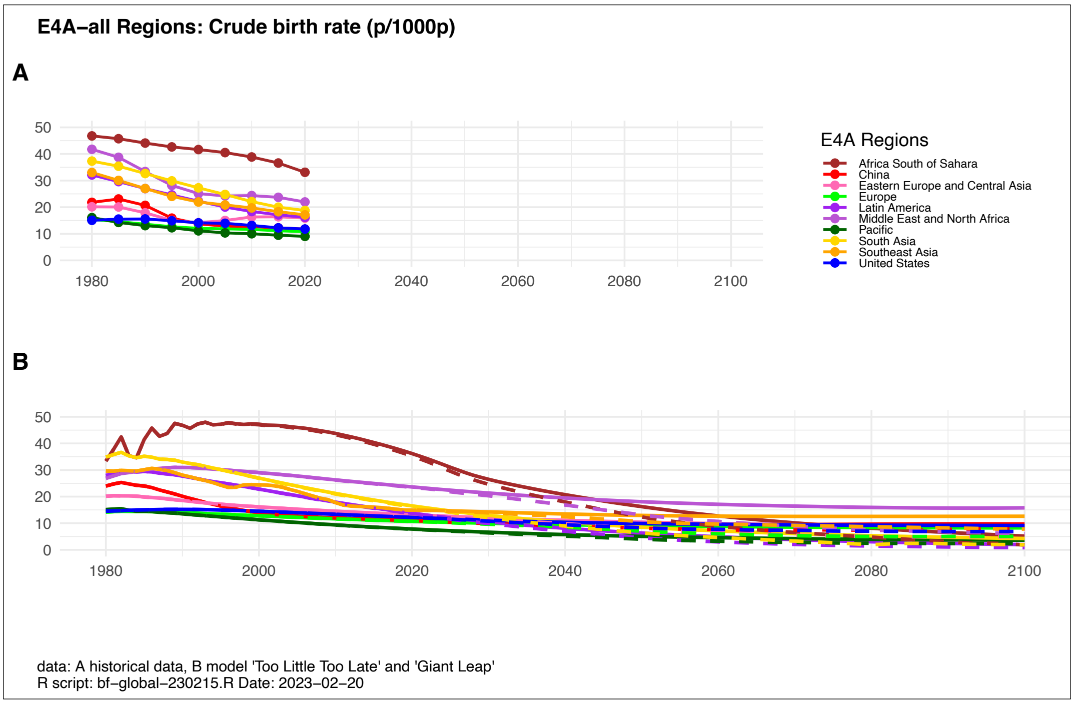
Earth4All is an international initiative to accelerate the systems changes we need for an equitable future on a finite planet. Combining the best available science with new economic thinking, Earth4All was designed to identify the transformations we need to create prosperity for all. Earth4All was initiated by The Club of Rome, the Potsdam Institute for Climate Impact Research, the Stockholm Resilience Centre and the Norwegian Business School. It builds on the legacies of *The Limits to Growth* and the planetary boundaries frameworks.

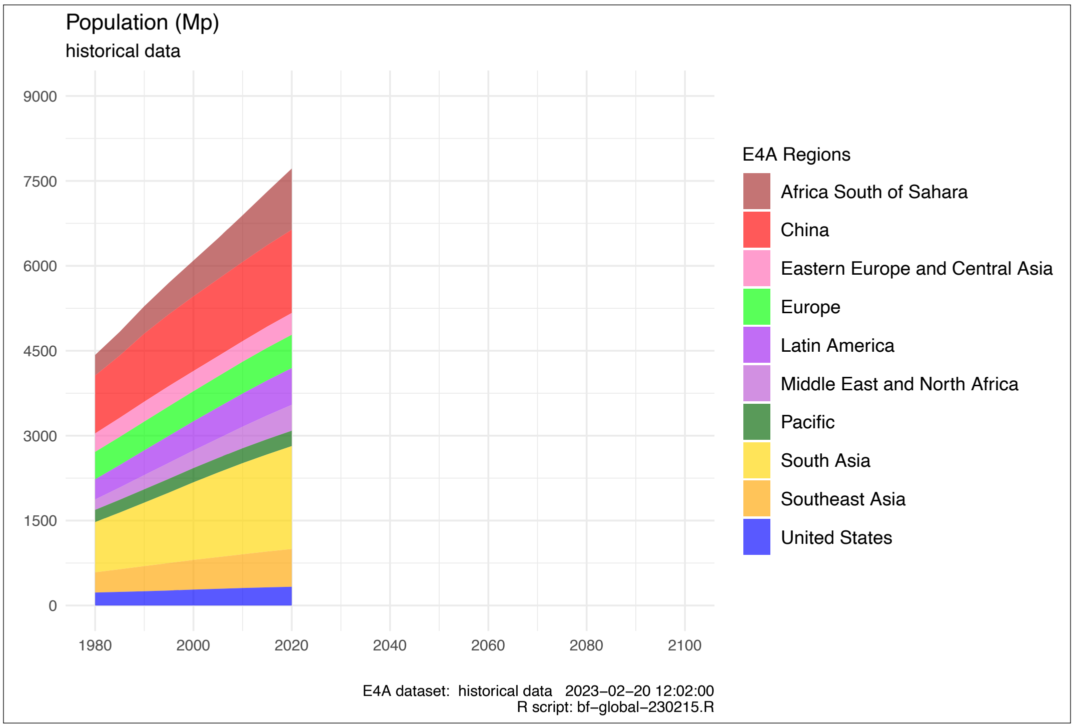
www.earth4all.life

Appendix 1 – Global data as sum of 10 regions

This appendix shows aggregated global population results based on all the 10 regions with 5-year cohorts. All charts are from the E4A-Regional-5y model.






Population (Mp)
historical data
9000
7500
6000
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E4A Regions
Africa South of Sahara
China
Eastern Europe and Central Asia
Europe
Latin America
Middle East and North Africa
Pacific
South Asia
Southeast Asia
United States
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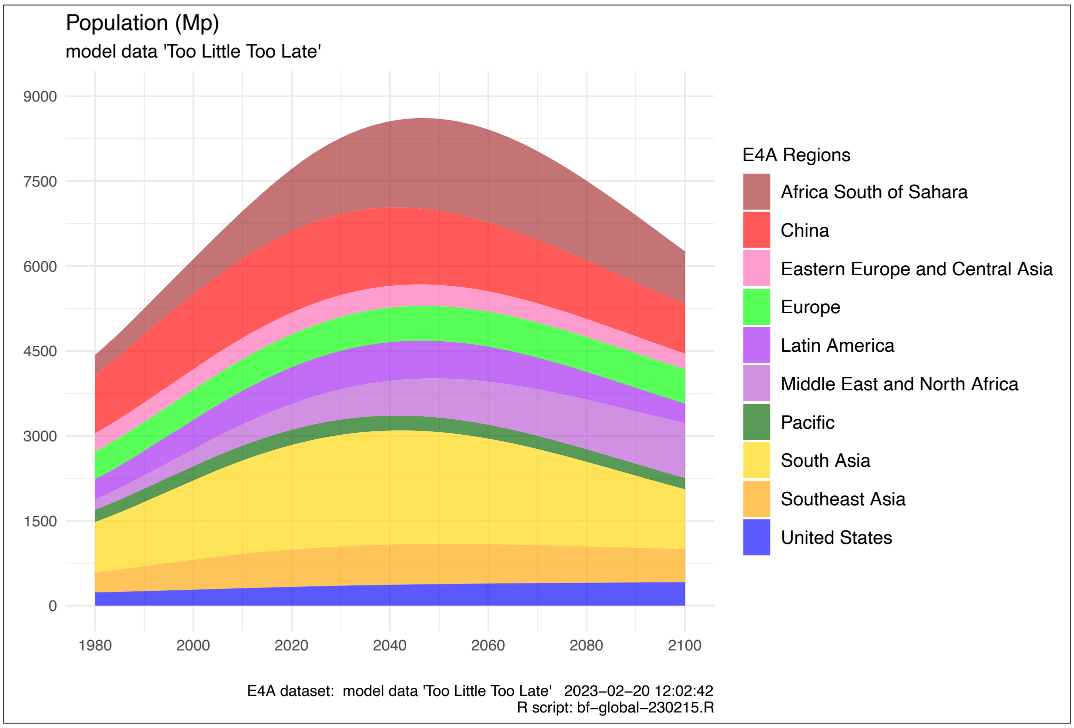
Population (Mp)
model data 'Too Little Too Late'
9000
7500
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E4A Regions
Africa South of Sahara
China
Eastern Europe and Central Asia
Europe
Latin America
Middle East and North Africa
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South Asia
Southeast Asia
United States
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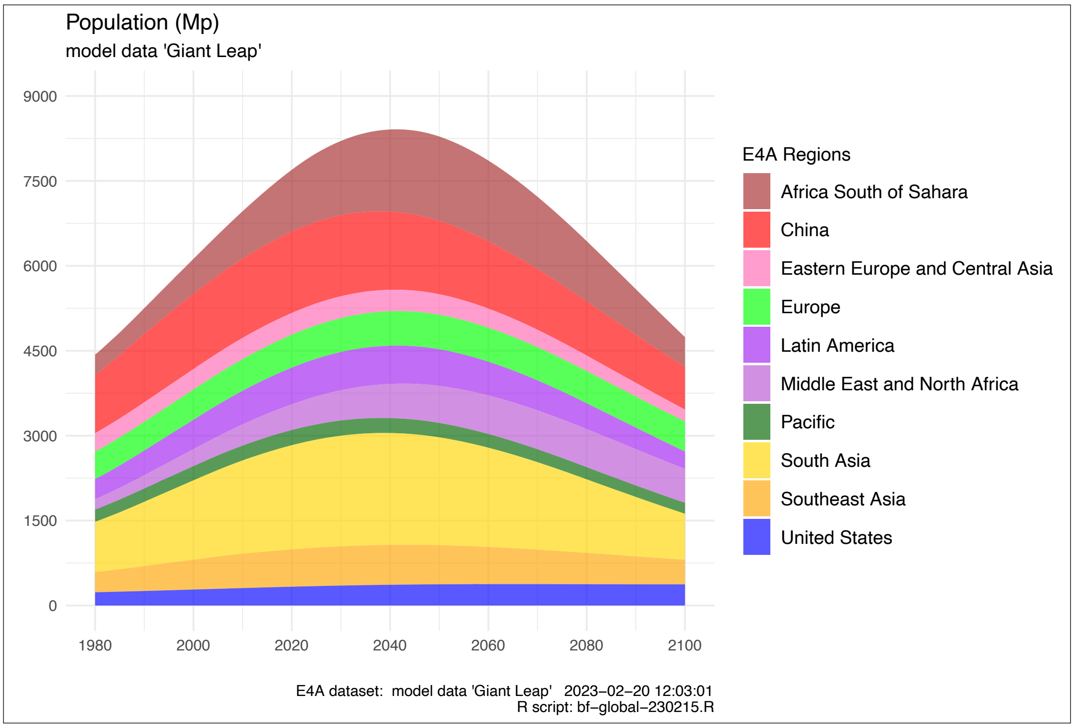
Population (Mp)
model data 'Giant Leap'
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E4A Regions
Africa South of Sahara
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Eastern Europe and Central Asia
Europe
Latin America
Middle East and North Africa
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South Asia
Southeast Asia
United States
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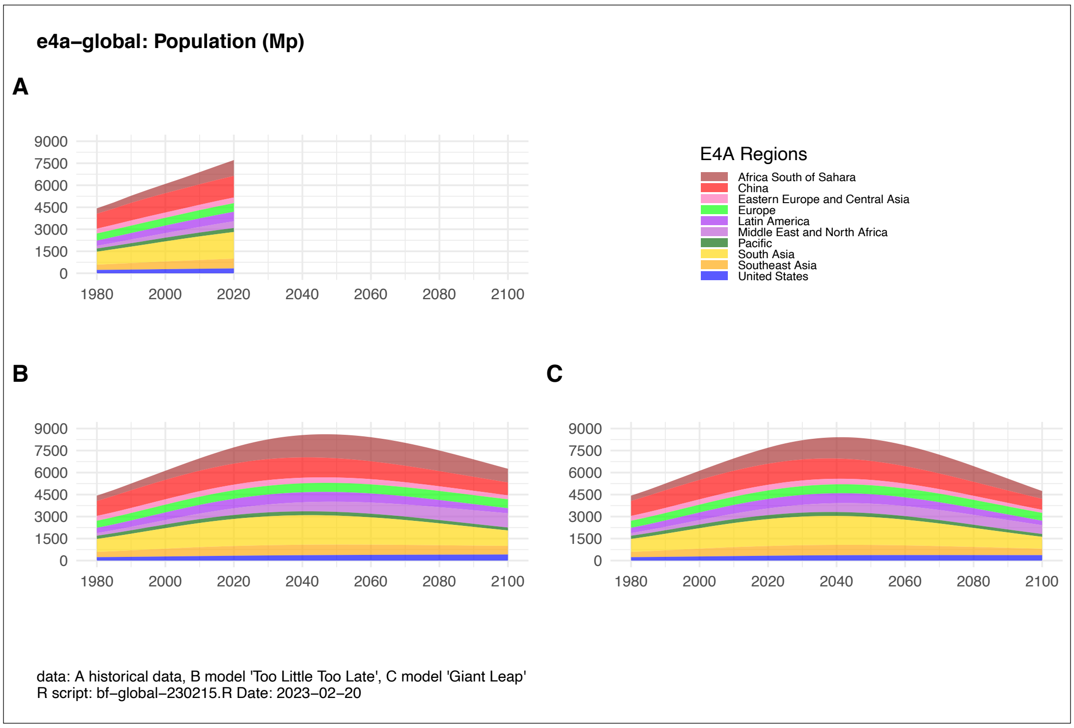
e4a–global: Population (Mp)
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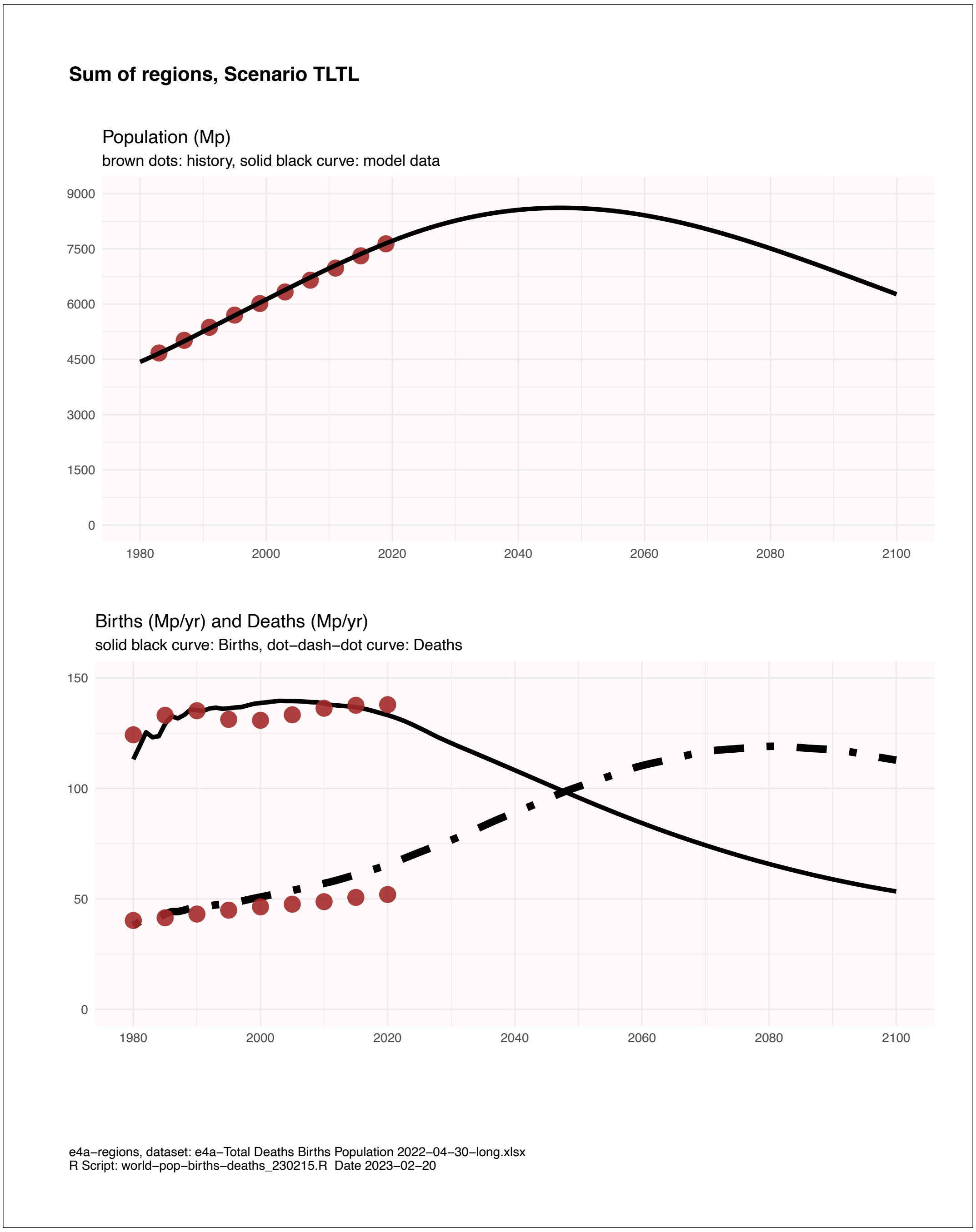
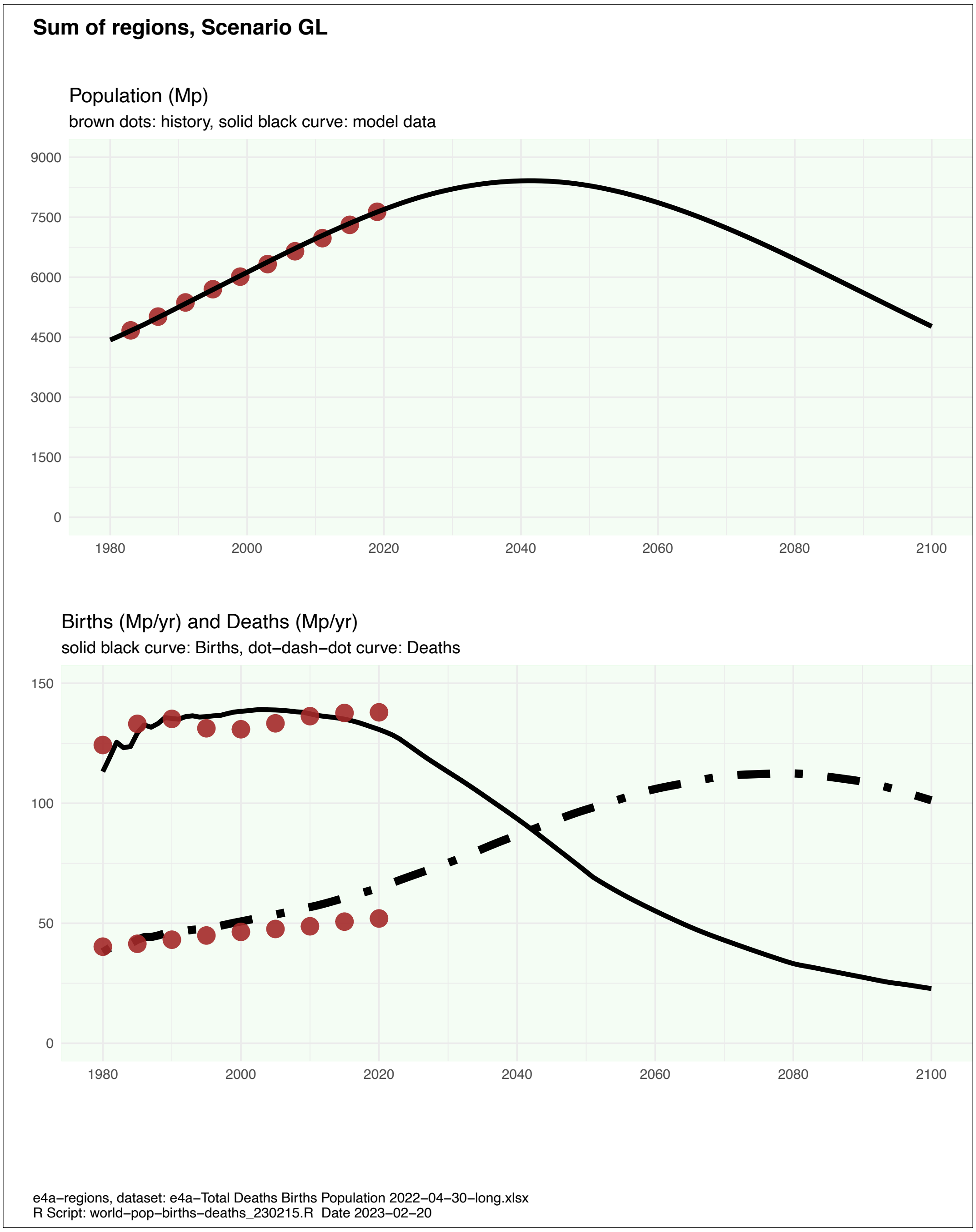
Middle East and North Africa
Pacific
South Asia
Southeast Asia
United States
data: A historical data, B model 'Too Little Too Late', C model 'Giant Leap'
R script: bf–global–230215.R Date: 2023–02–20


Sum of regions, Scenario TLTL
Population (Mp)
brown dots: history, solid black curve: model data
9000
7500
6000
4500
3000
1500
0
1980
2000
2020
2040
2060
2080
2100
Births (Mp/yr) and Deaths (Mp/yr)
solid black curve: Births, dot–dash–dot curve: Deaths
150
100
50
0
1980
2000
2020
2040
2060
2080
2100
e4a–regions, dataset: e4a–Total Deaths Births Population 2022–04–30–long.xlsx
R Script: world–pop–births–deaths_230215.R Date 2023–02–20


Sum of regions, Scenario GL
Population (Mp)
brown dots: history, solid black curve: model data
9000
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2000
2020
2040
2060
2080
2100
Births (Mp/yr) and Deaths (Mp/yr)
solid black curve: Births, dot–dash–dot curve: Deaths
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2020
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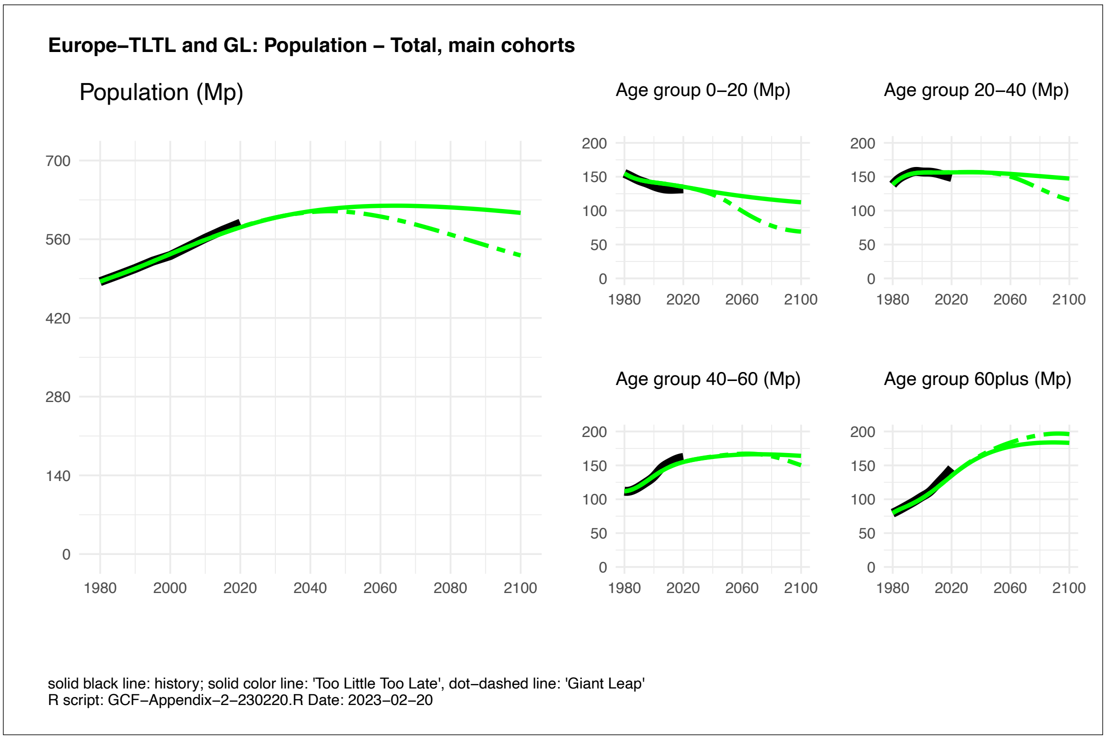
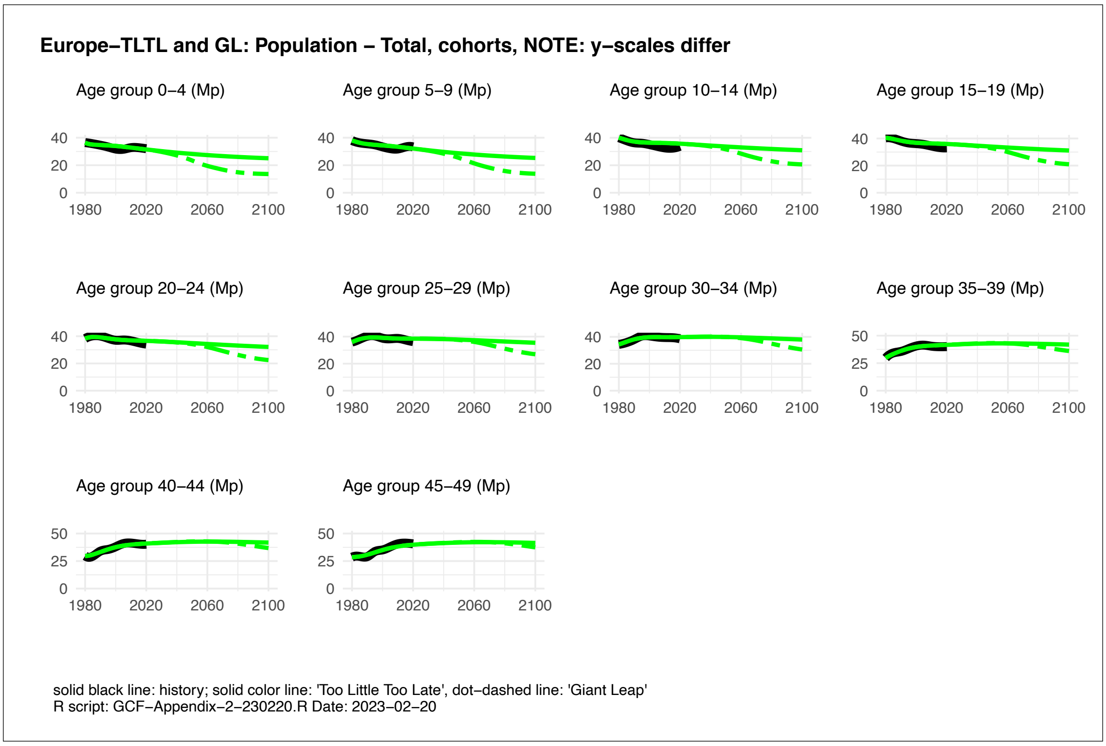
2080
2100
e4a–regions, dataset: e4a–Total Deaths Births Population 2022–04–30–long.xlsx
R Script: world–pop–births–deaths_230215.R Date 2023–02–20

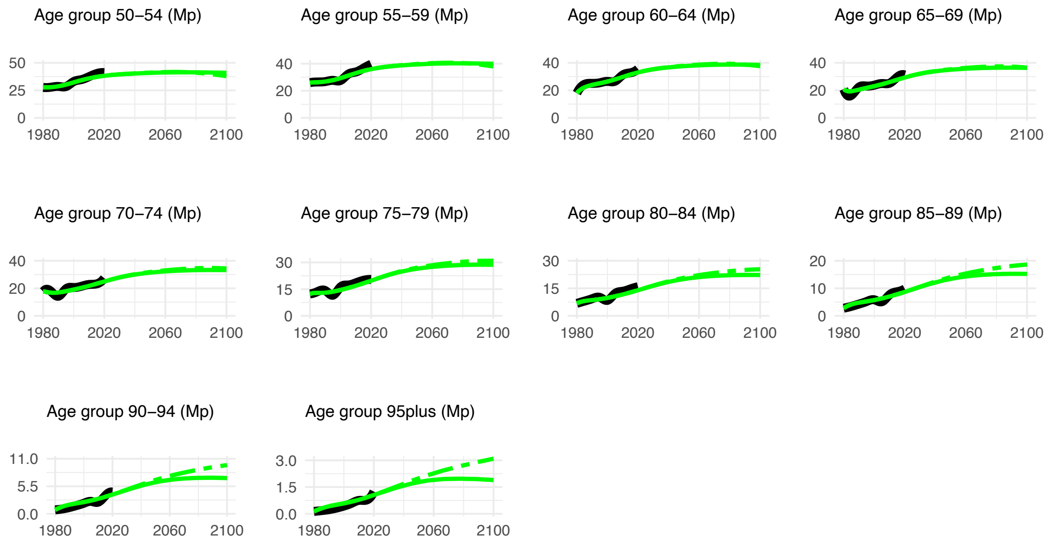
Appendix 2 – Regional data

Regional Data E4A – Europe demographics 1980–2100 (all regions have similar breakdown)



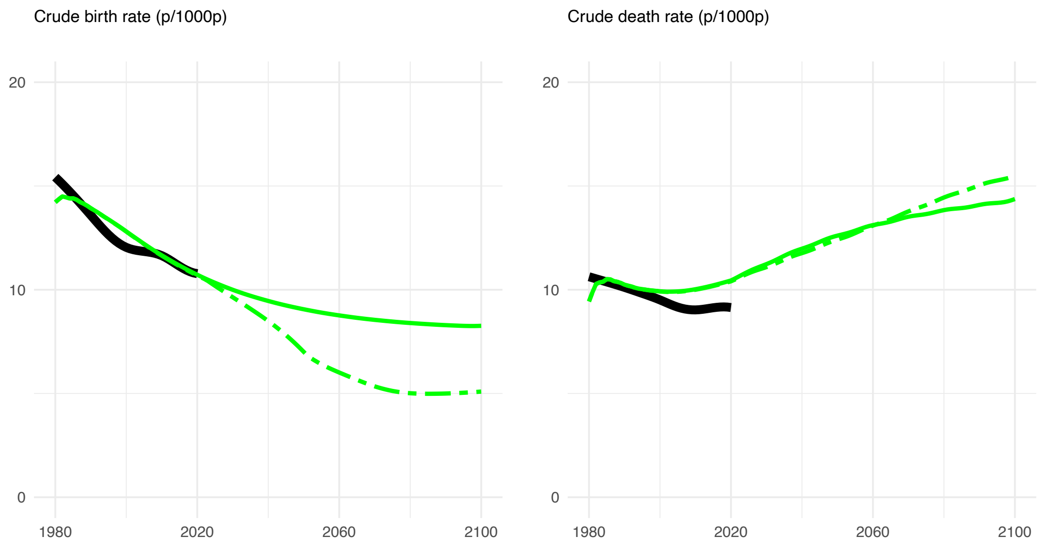


Europe–TLTL and GL: Population – Total, cohorts, NOTE: y-scales differ



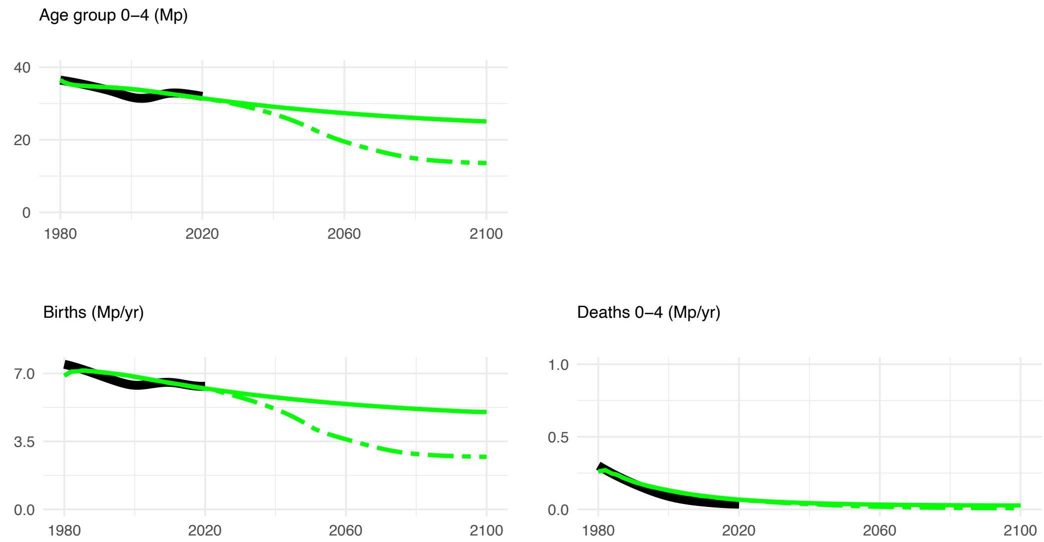
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Europe–TLTL and GL: Crude birth and death rates



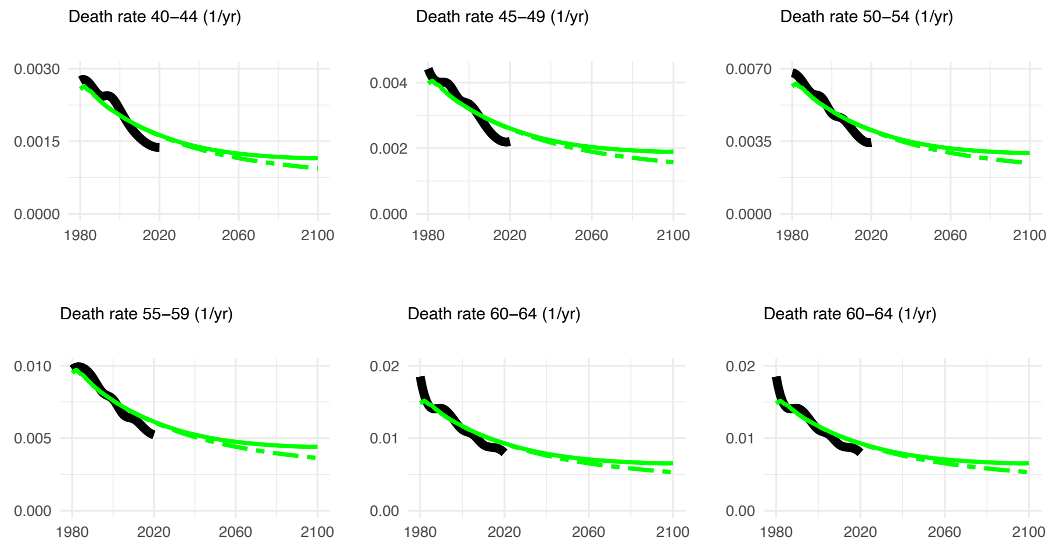
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Europe–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ

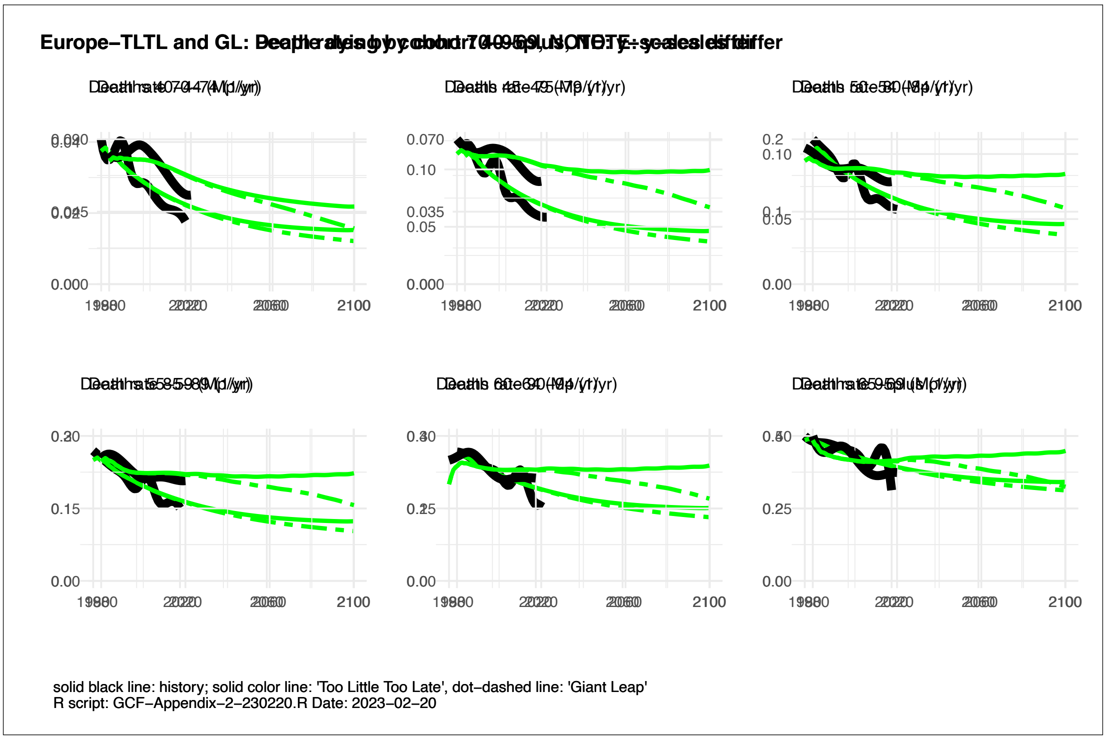


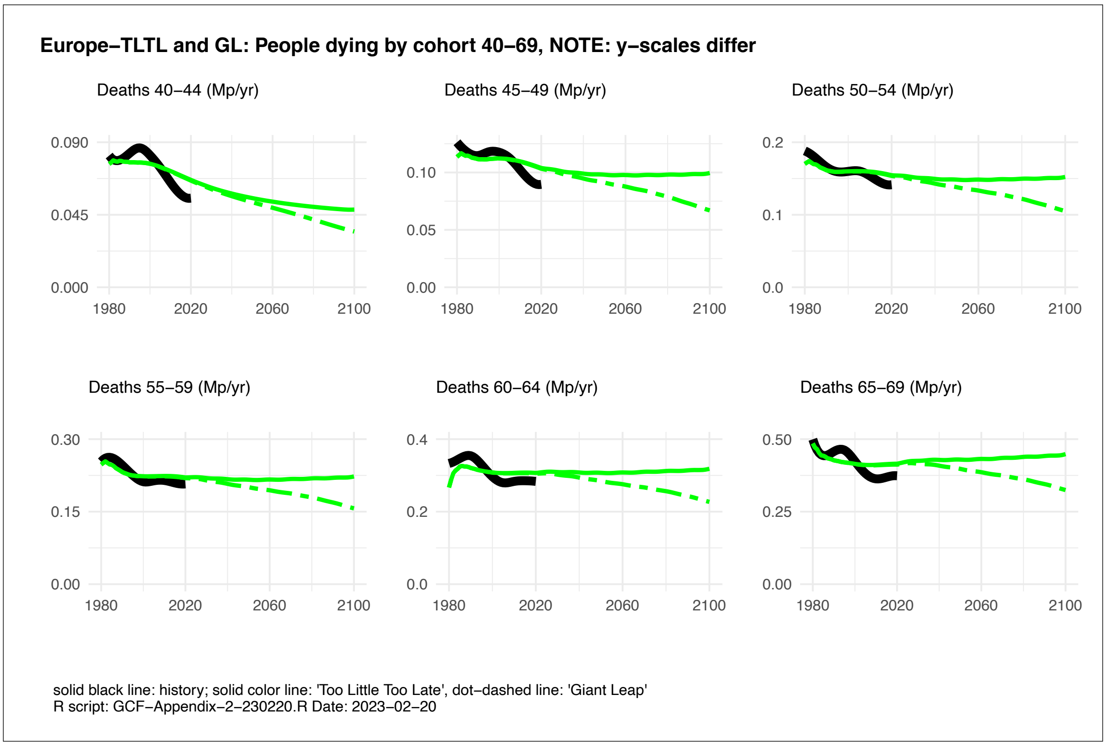
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

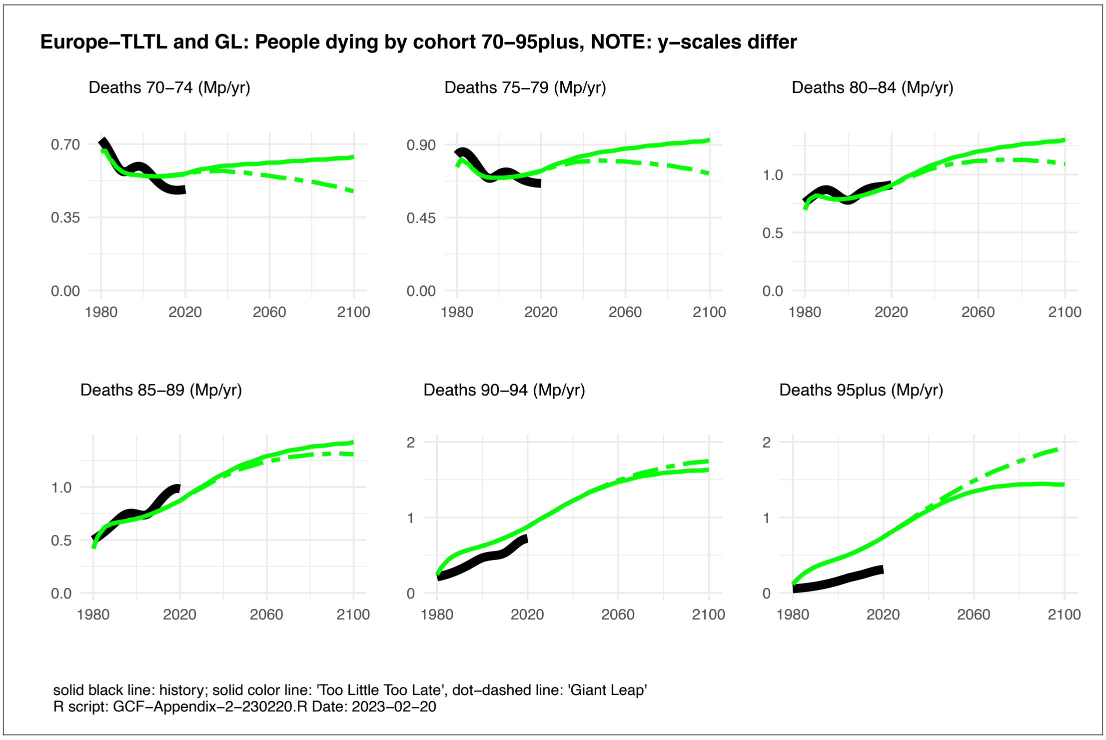
Europe–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ



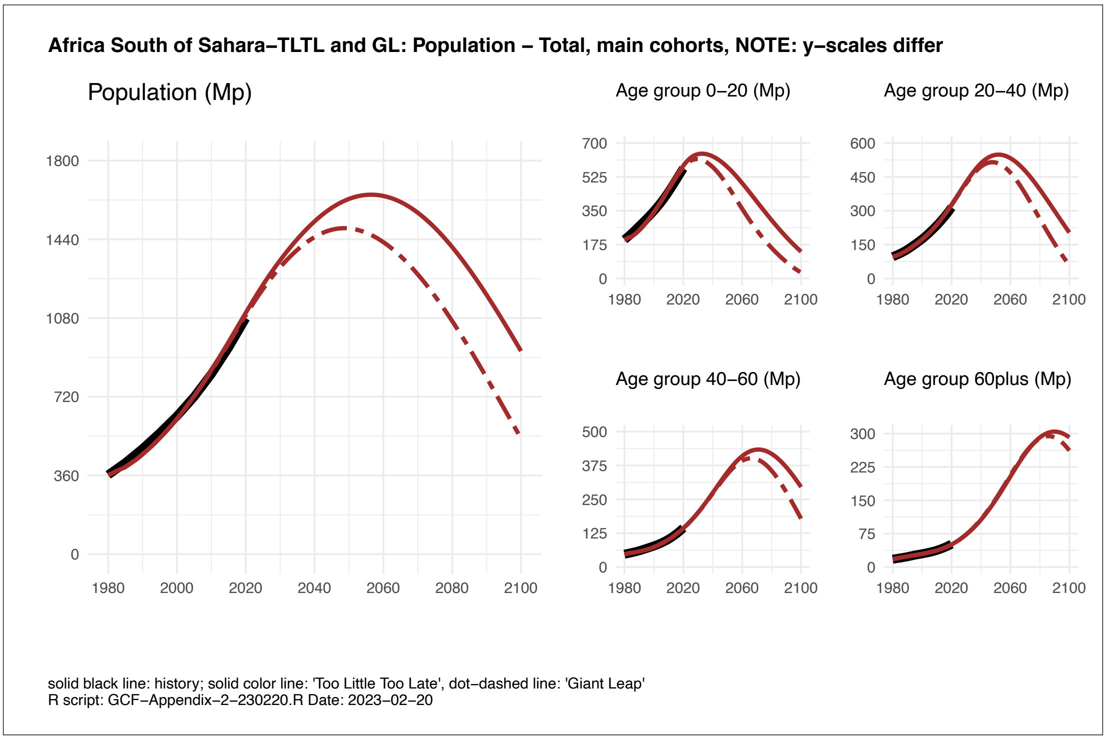
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

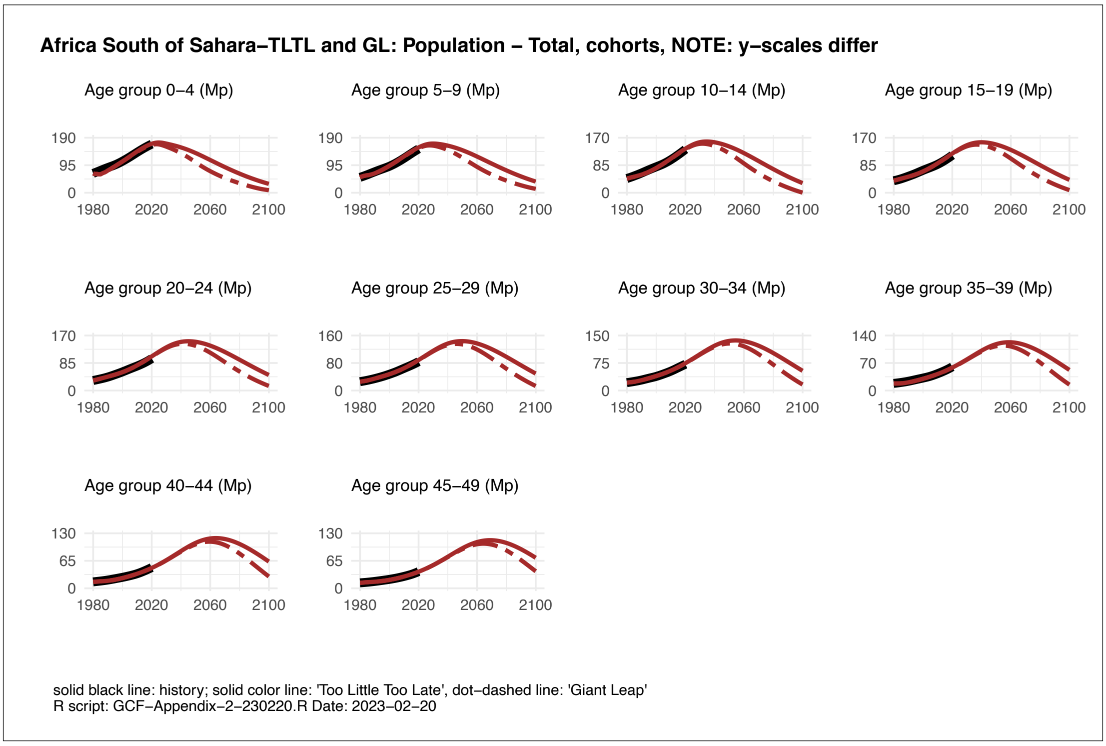

solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Europe–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

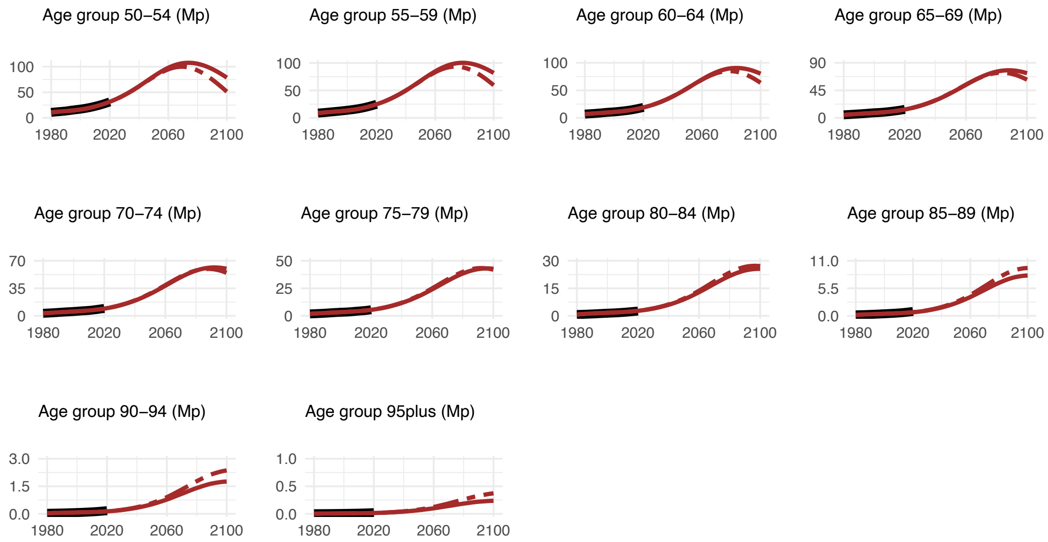

Europe–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
0.70
0.35
0.00
0.90
0.45
1.0
0.5
0.0
2
1
0
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Regional Data E4A – Africa South of Sahara demographics 1980–2100



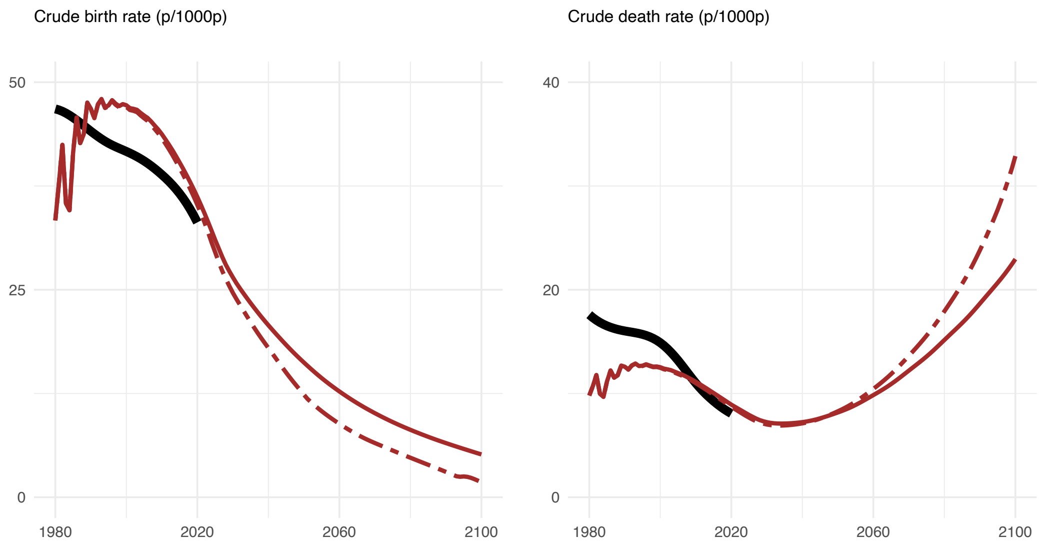


Africa South of Sahara–TLTL and GL: Population – Total, cohorts, NOTE: y-scales differ

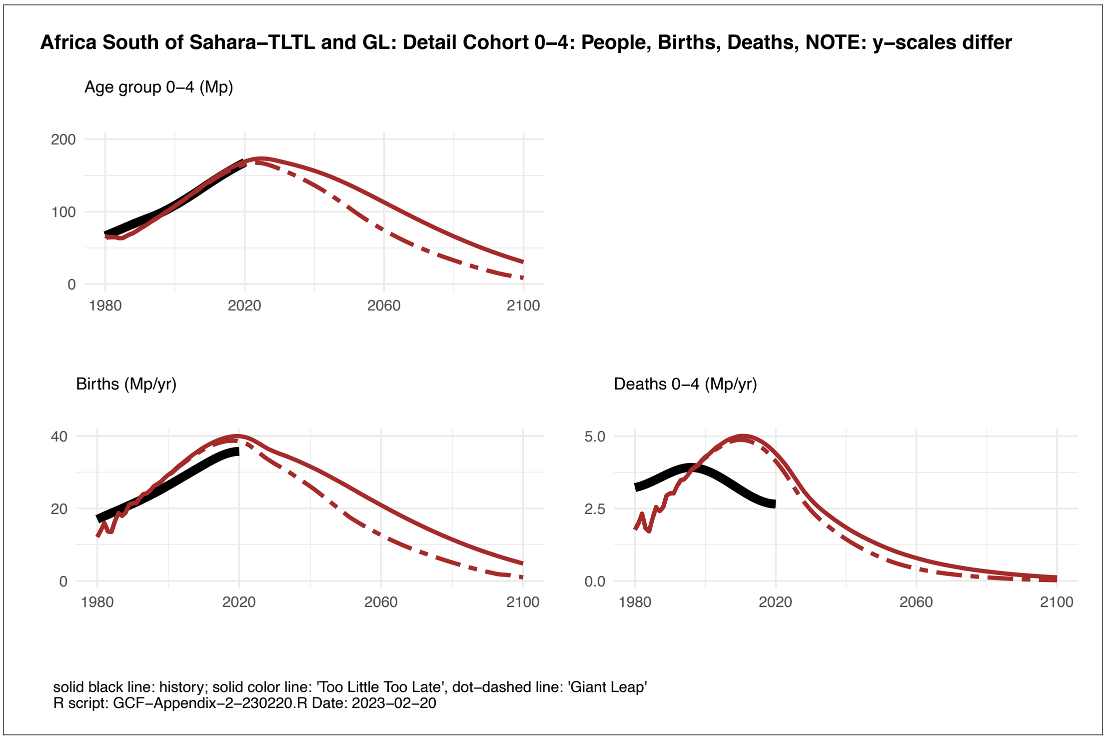


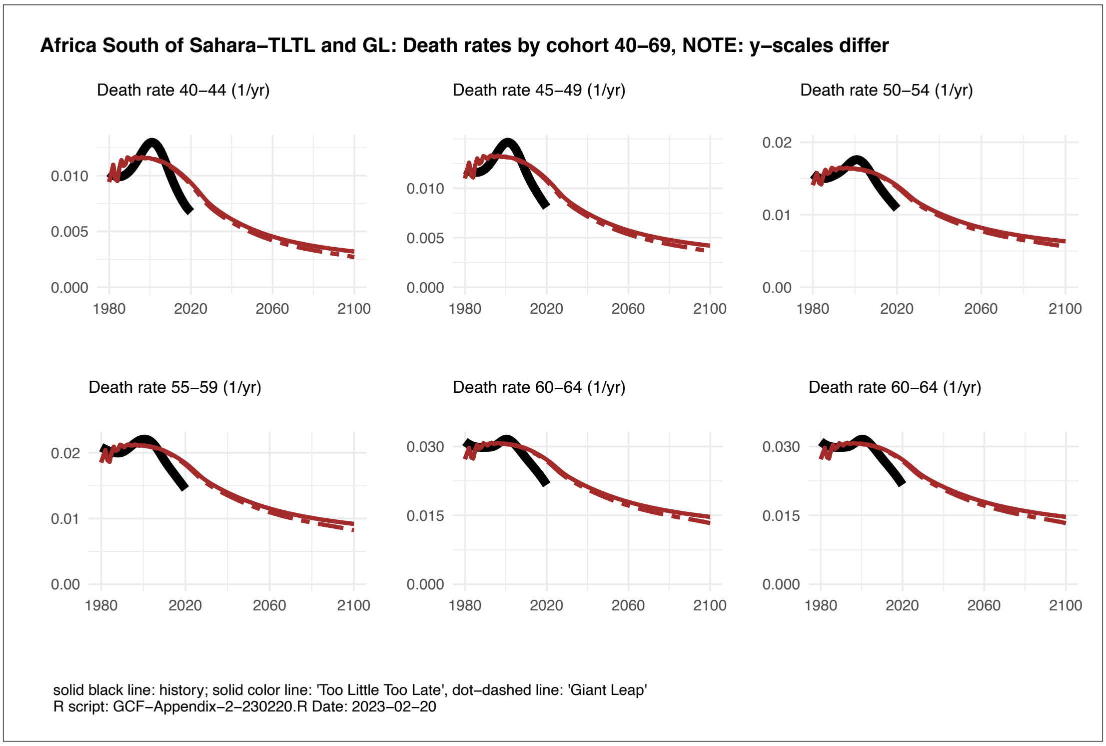
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

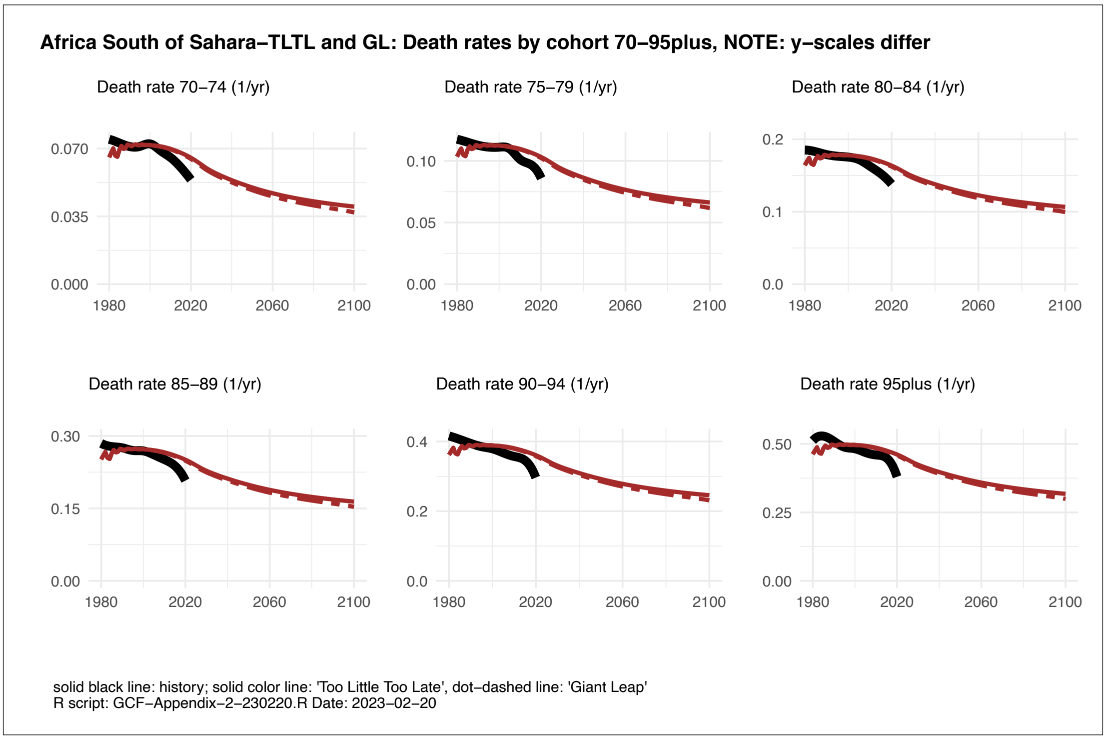
Africa South of Sahara–TLTL and GL: Crude birth and death rates, NOTE y-scales may differ

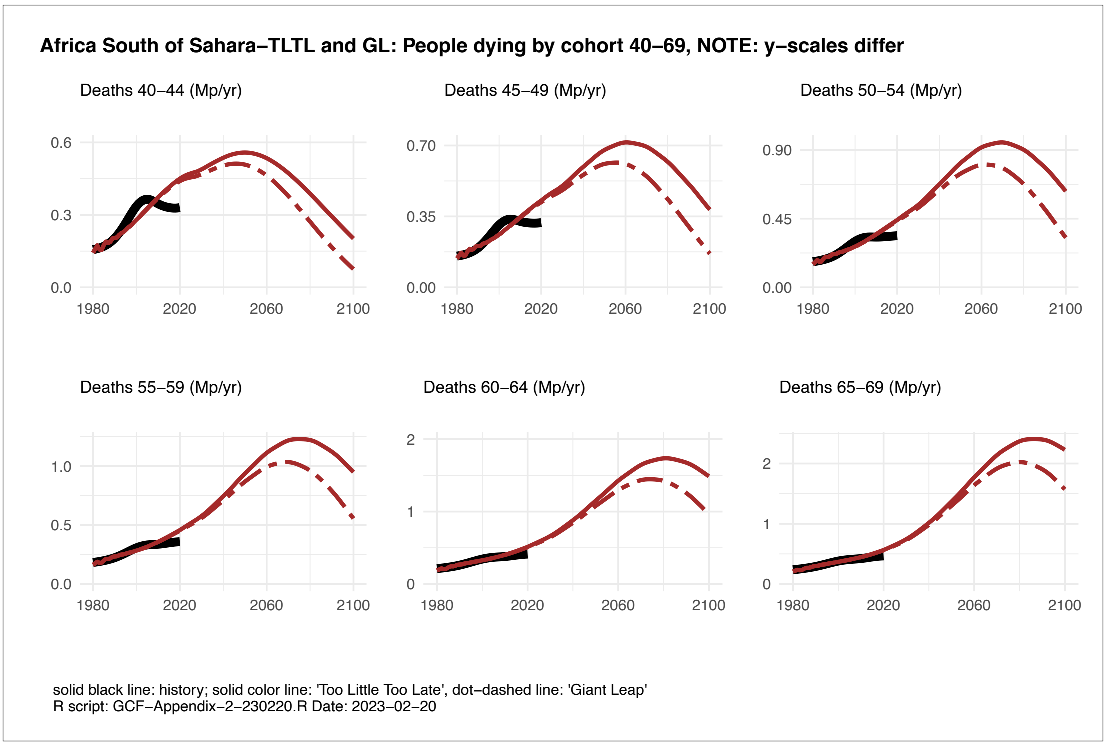


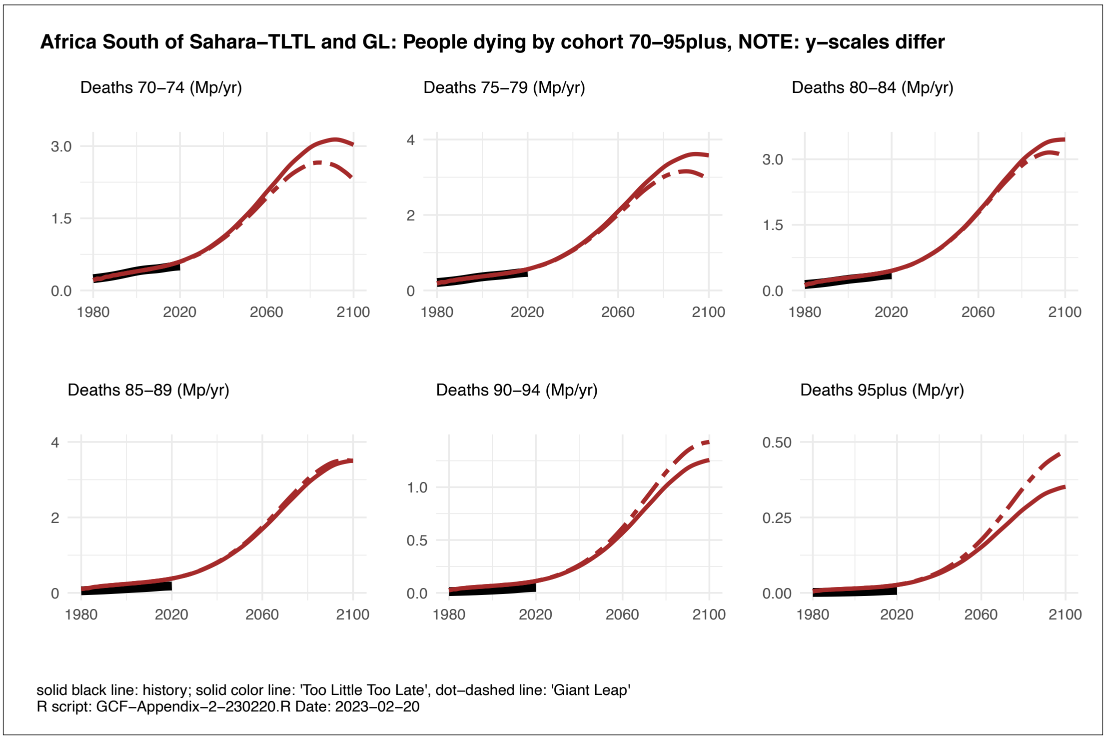
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Africa South of Sahara–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
200
100
0
1980
2020
2060
2100
Births (Mp/yr)
40
20
0
Deaths 0–4 (Mp/yr)
5.0
2.5
0.0
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

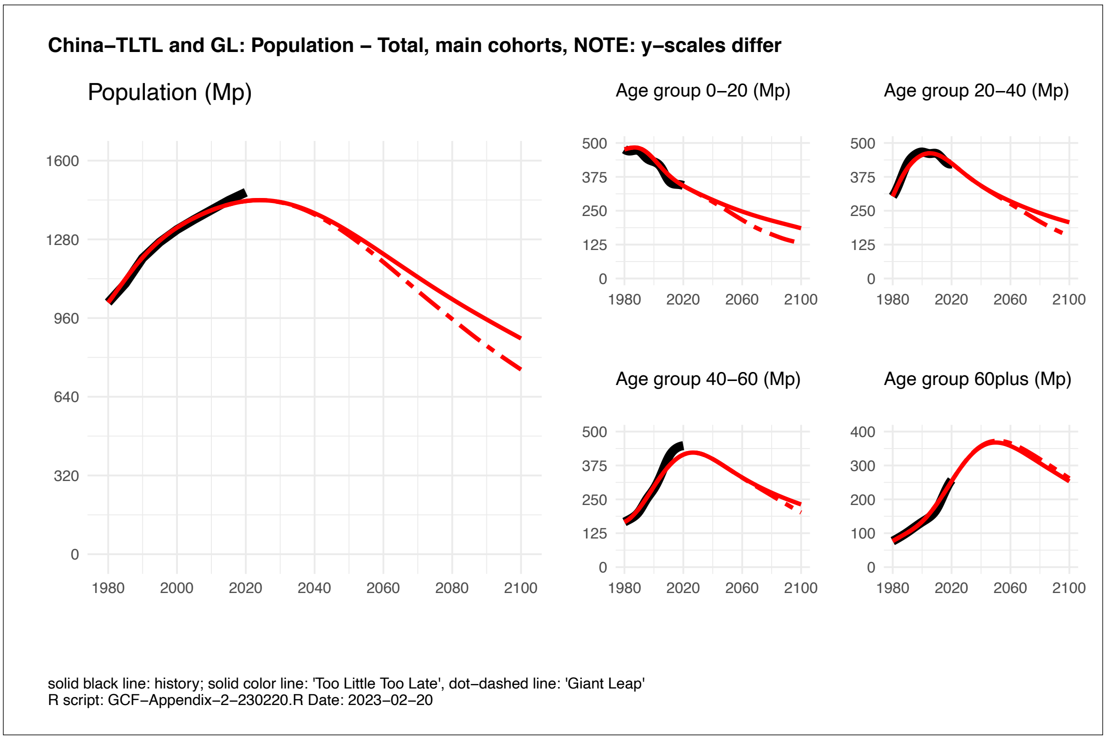

Africa South of Sahara–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
Death rate 45–49 (1/yr)
Death rate 50–54 (1/yr)
0.010
0.005
0.000
0.02
0.01
0.00
1980
2020
2060
2100
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
Death rate 60–64 (1/yr)
0.030
0.015
0.000
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

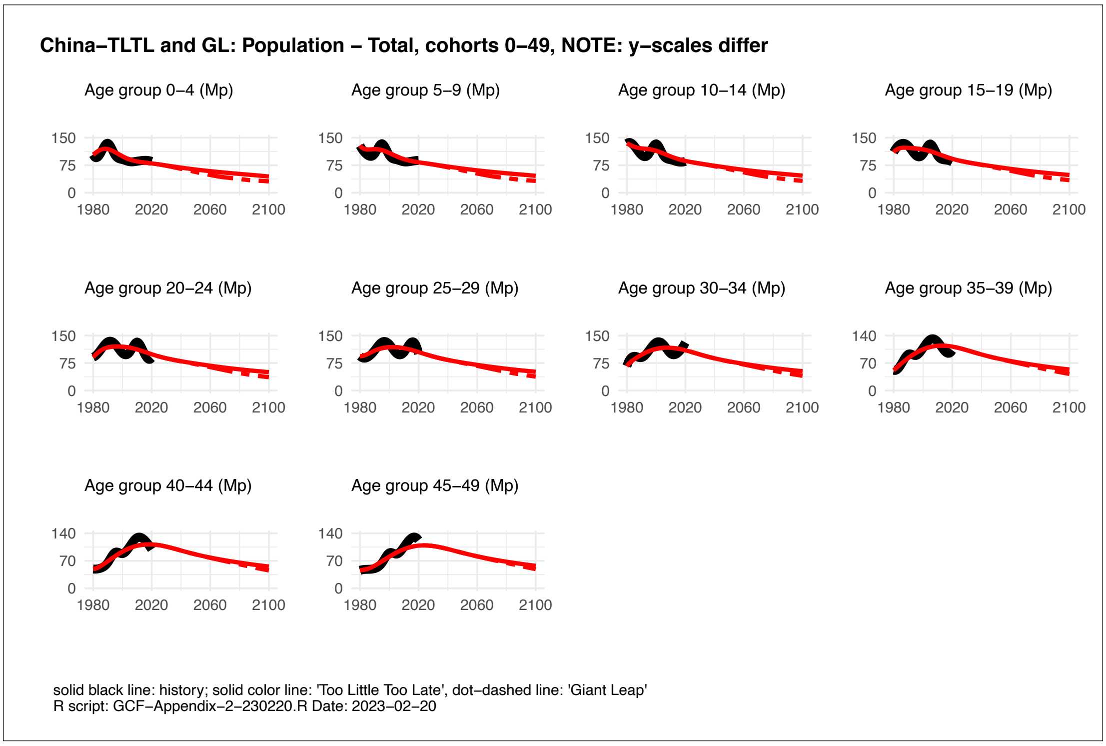

Africa South of Sahara–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

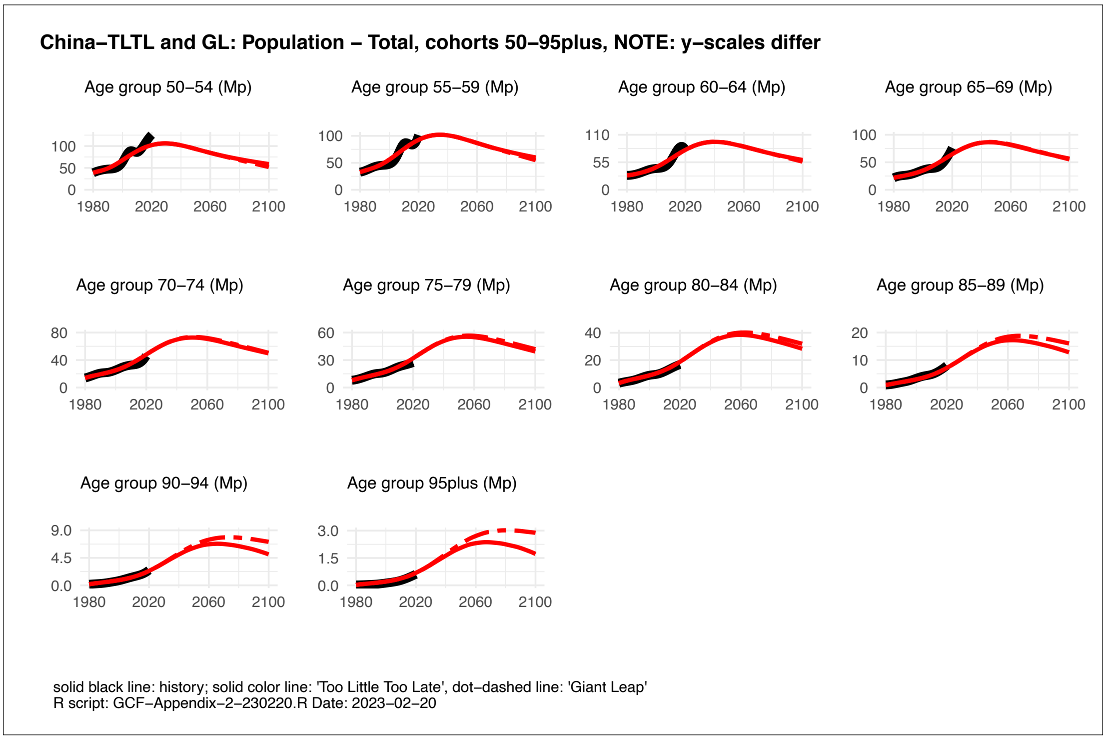

Africa South of Sahara–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

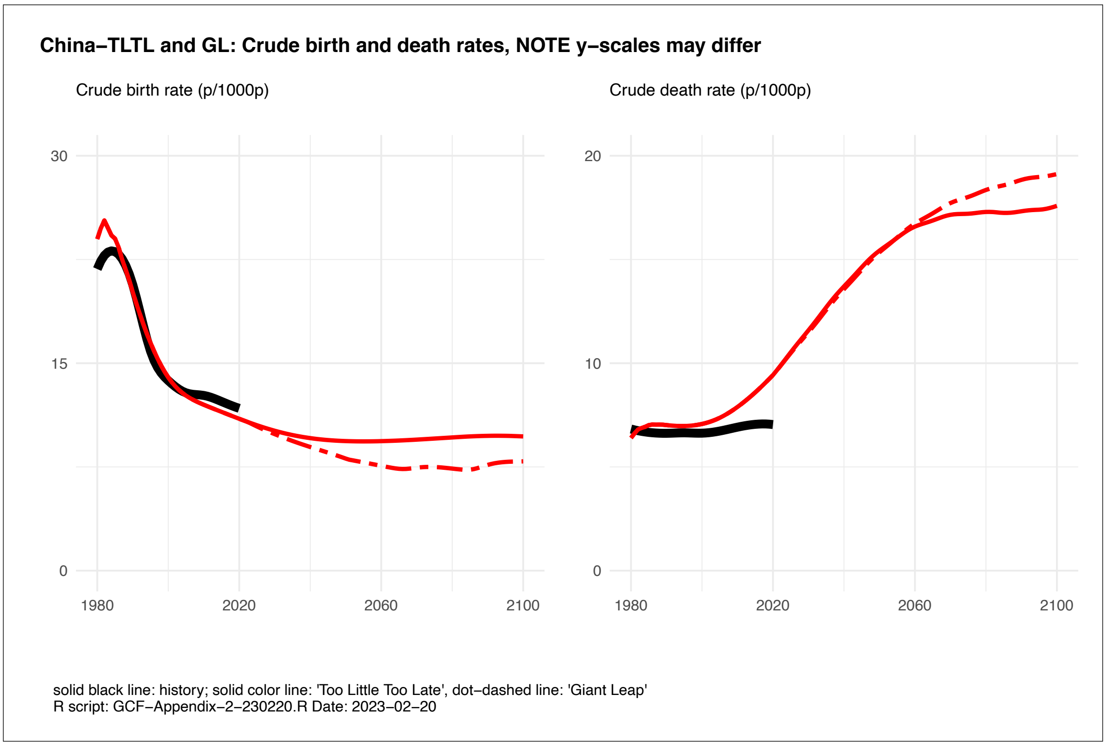

Africa South of Sahara–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

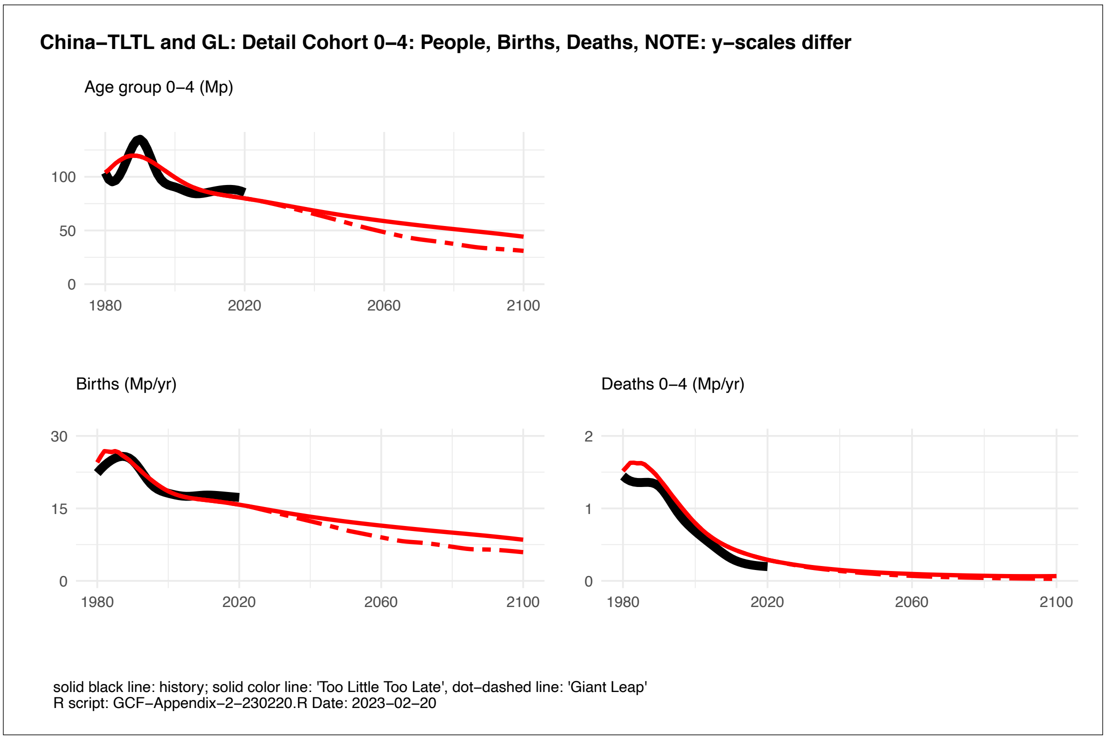
Regional Data E4A – China demographics 1980–2100

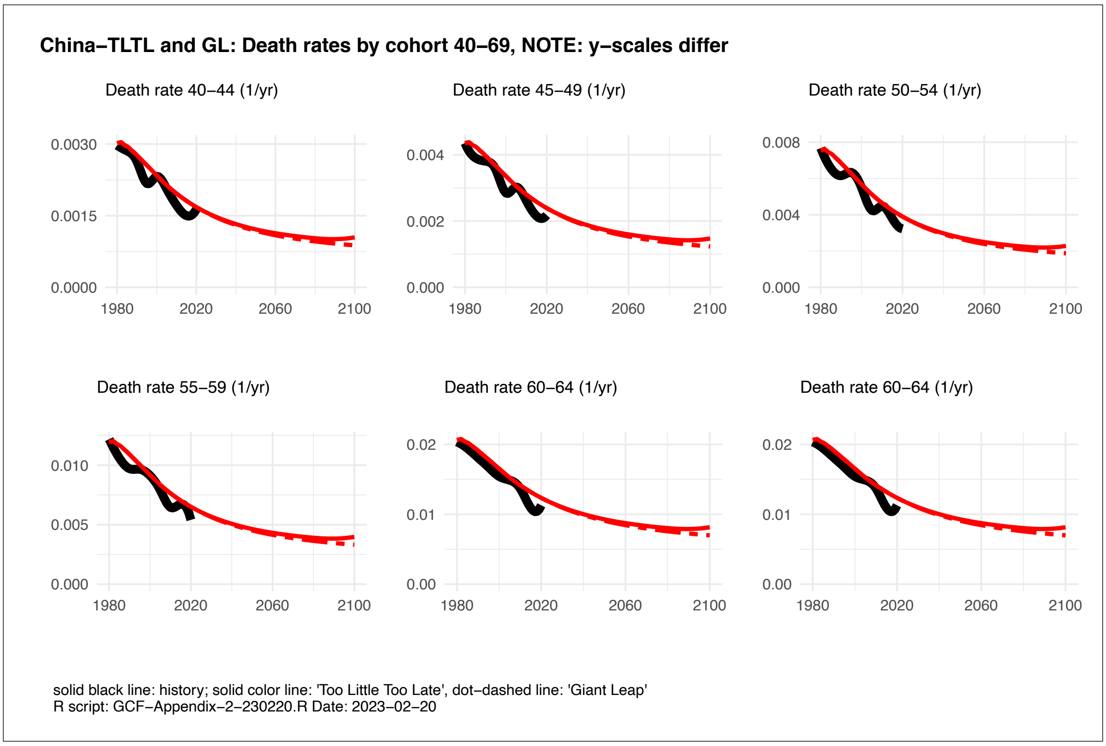


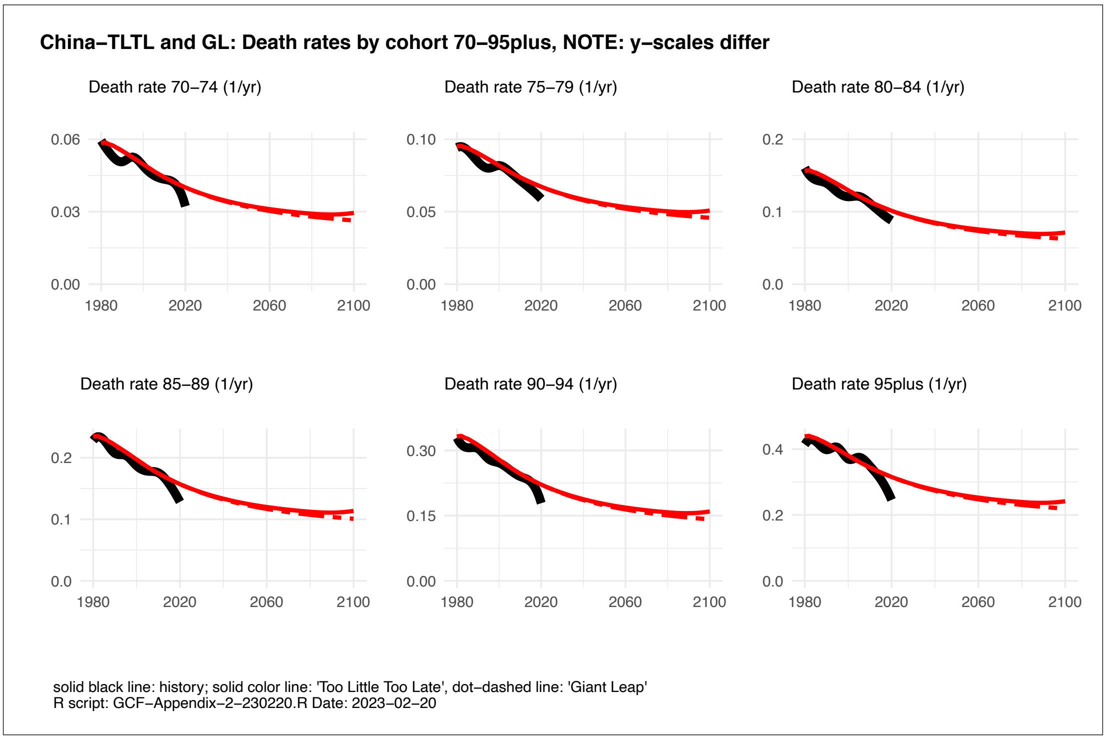


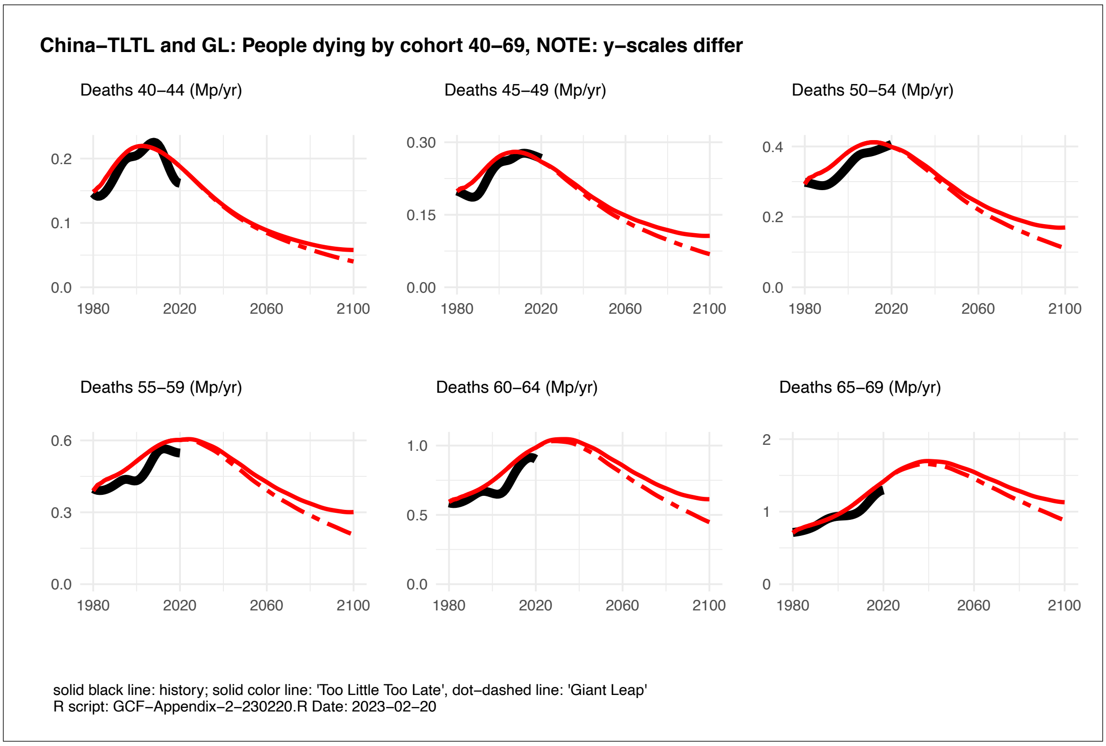

China–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

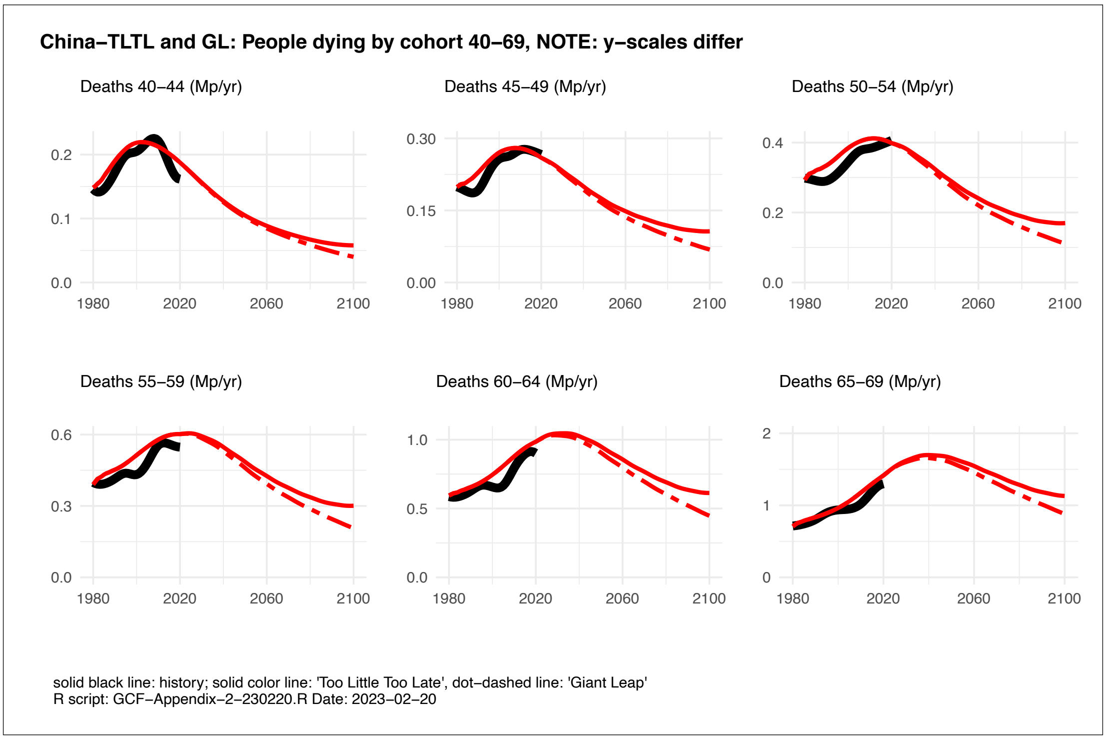

China–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


China–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
Births (Mp/yr)
Deaths 0–4 (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

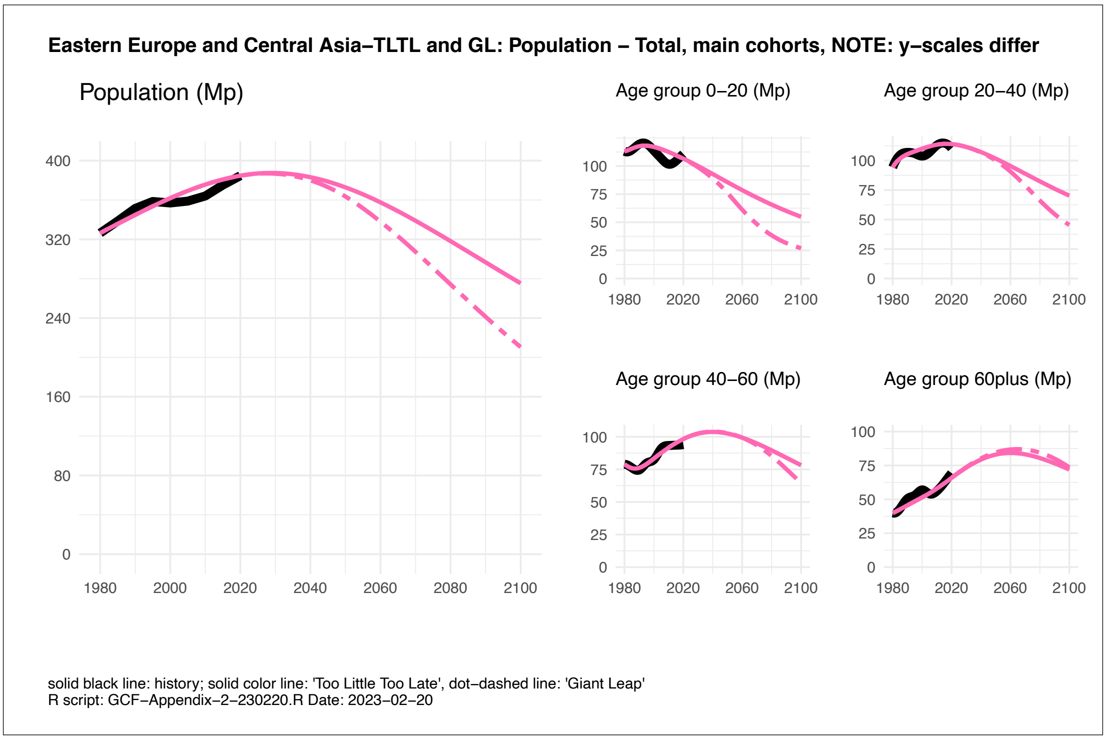

China–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
Death rate 45–49 (1/yr)
Death rate 50–54 (1/yr)
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
Death rate 60–64 (1/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

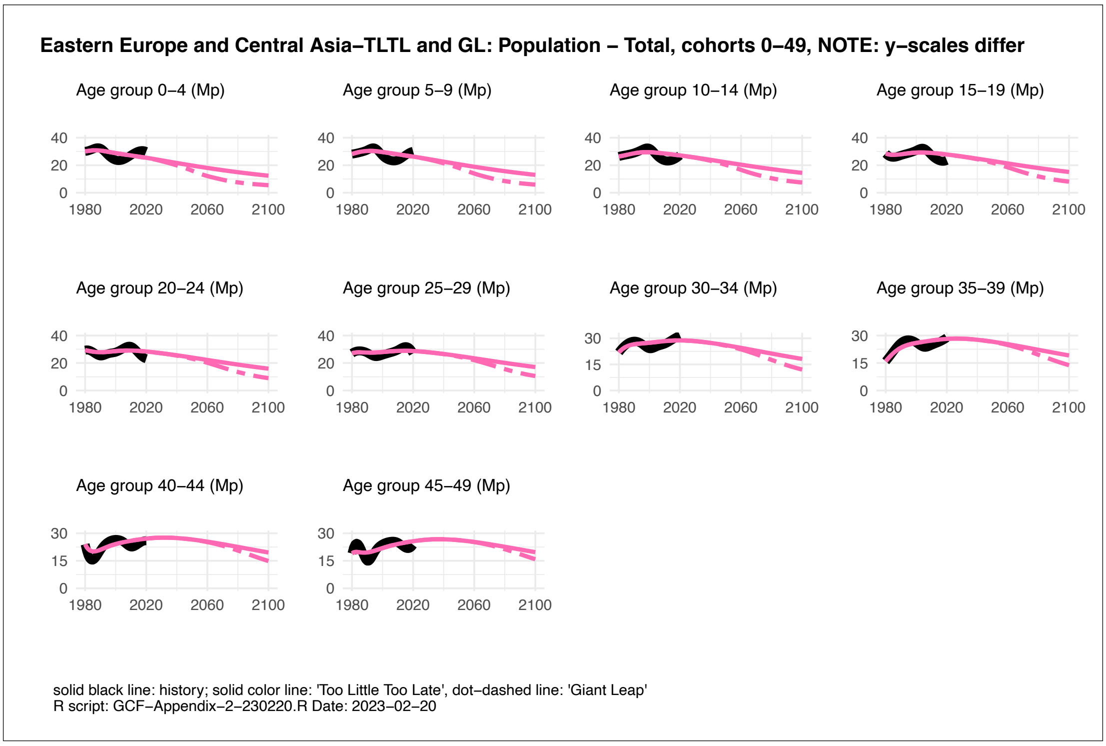

China–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

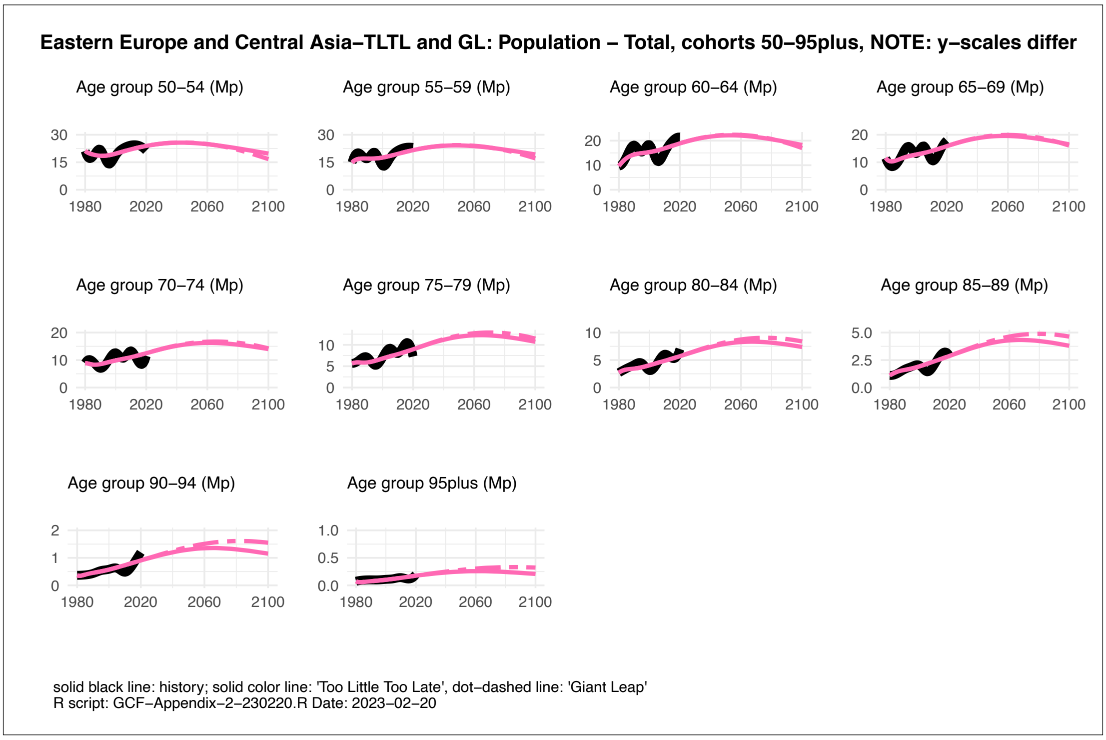

China–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

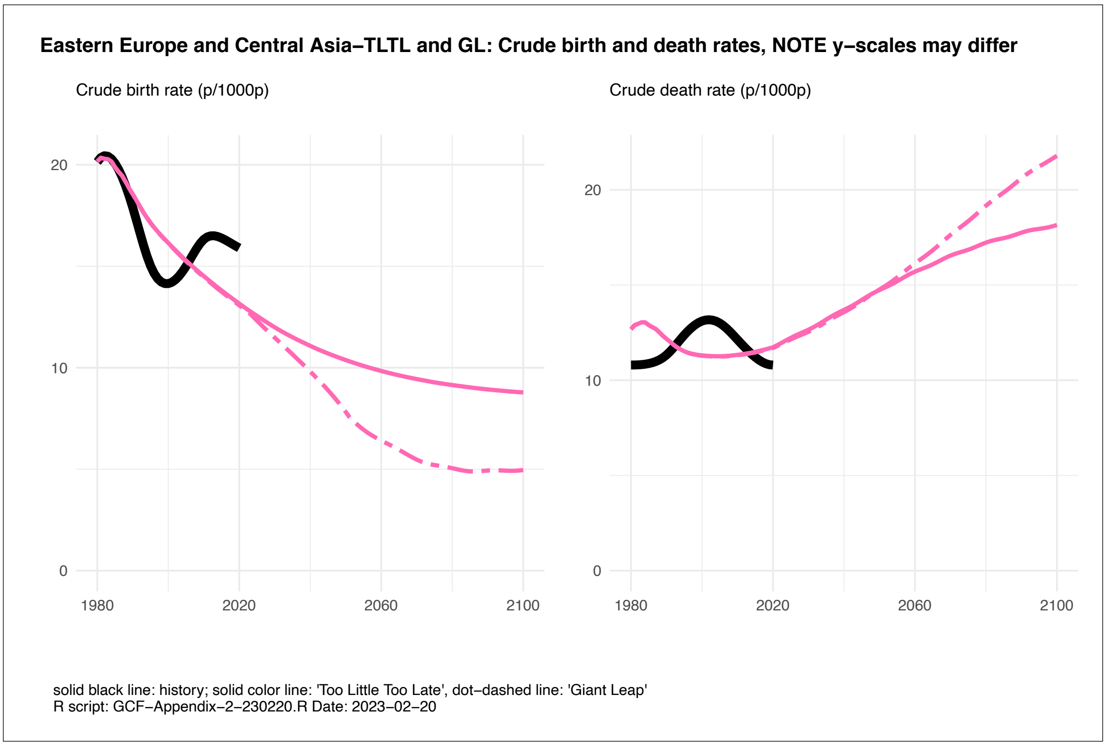

China–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

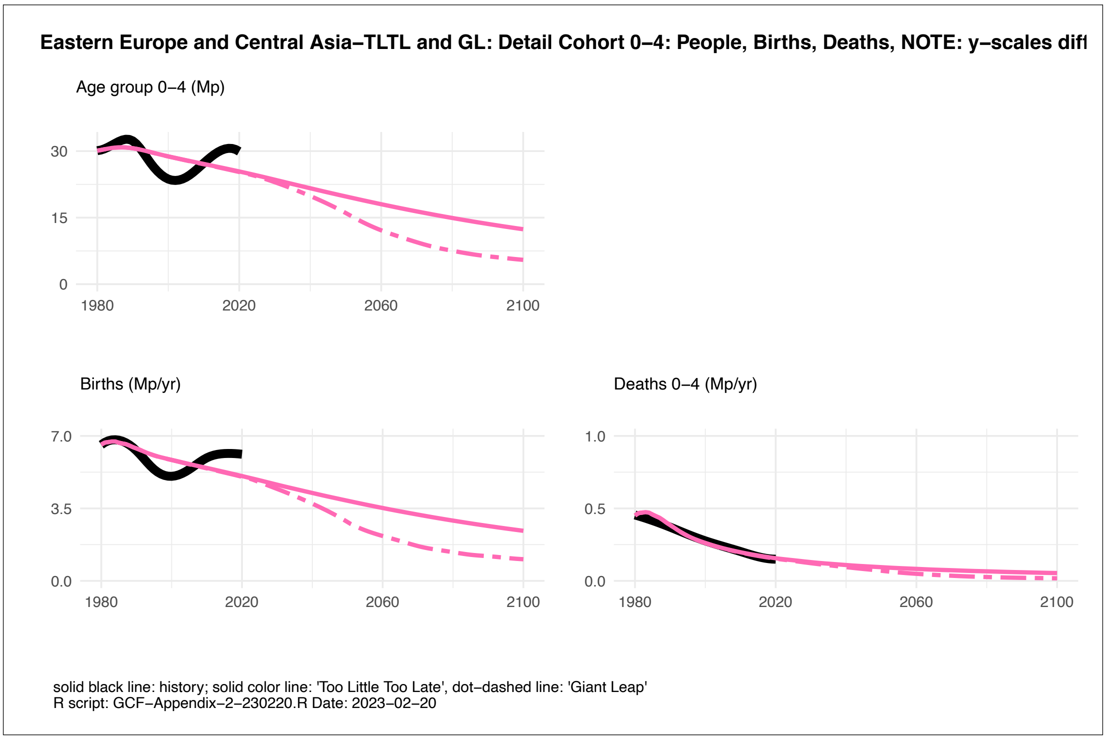
Regional Data E4A – Eastern Europe & Central Asia demographics 1980–2100

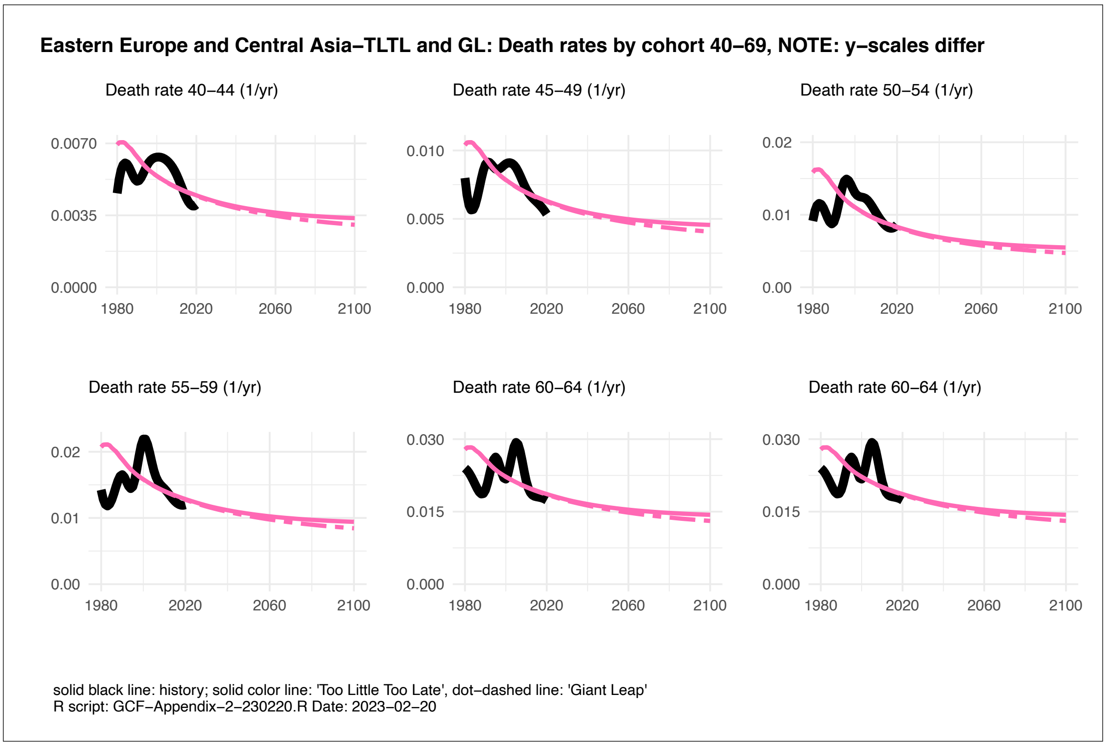




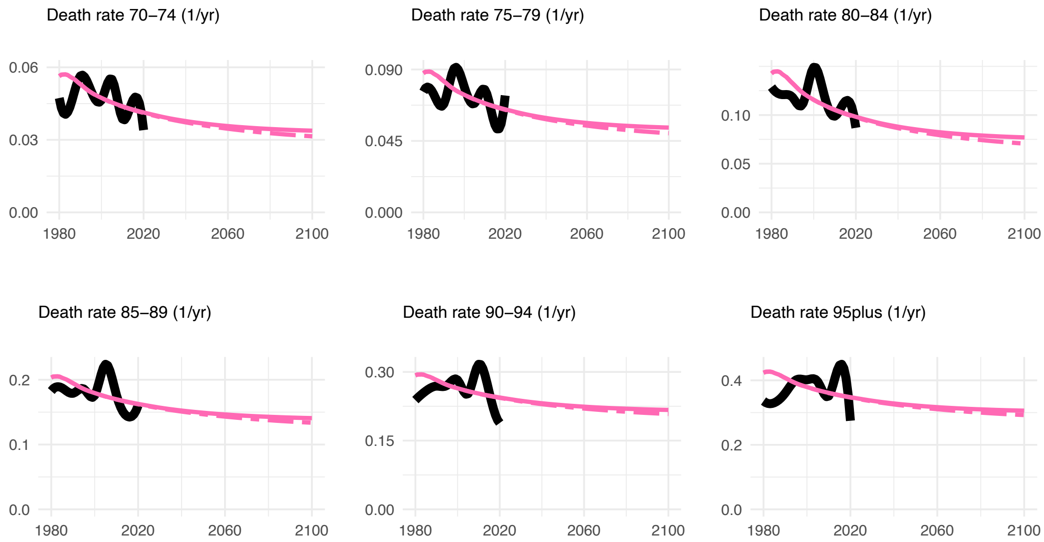

Eastern Europe and Central Asia–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Eastern Europe and Central Asia–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Eastern Europe and Central Asia–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales diff
Age group 0–4 (Mp)
30
15
0
1980
2020
2060
2100
Births (Mp/yr)
7.0
3.5
0.0
Deaths 0–4 (Mp/yr)
1.0
0.5
0.0
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

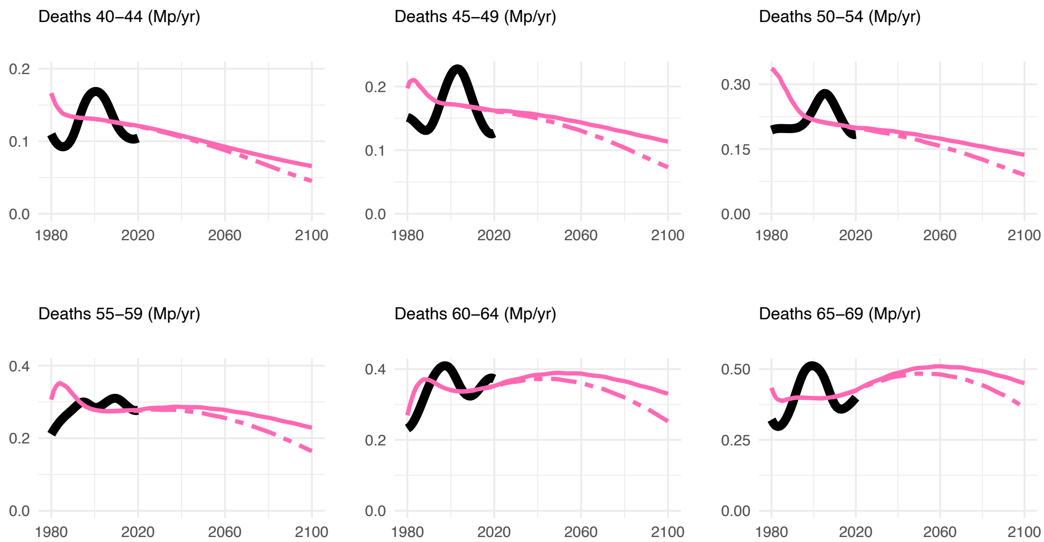

Eastern Europe and Central Asia–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
0.0070
0.0035
0.0000
Death rate 45–49 (1/yr)
0.010
0.005
0.000
Death rate 50–54 (1/yr)
0.02
0.01
0.00
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
0.030
0.015
Death rate 60–64 (1/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Eastern Europe and Central Asia–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ

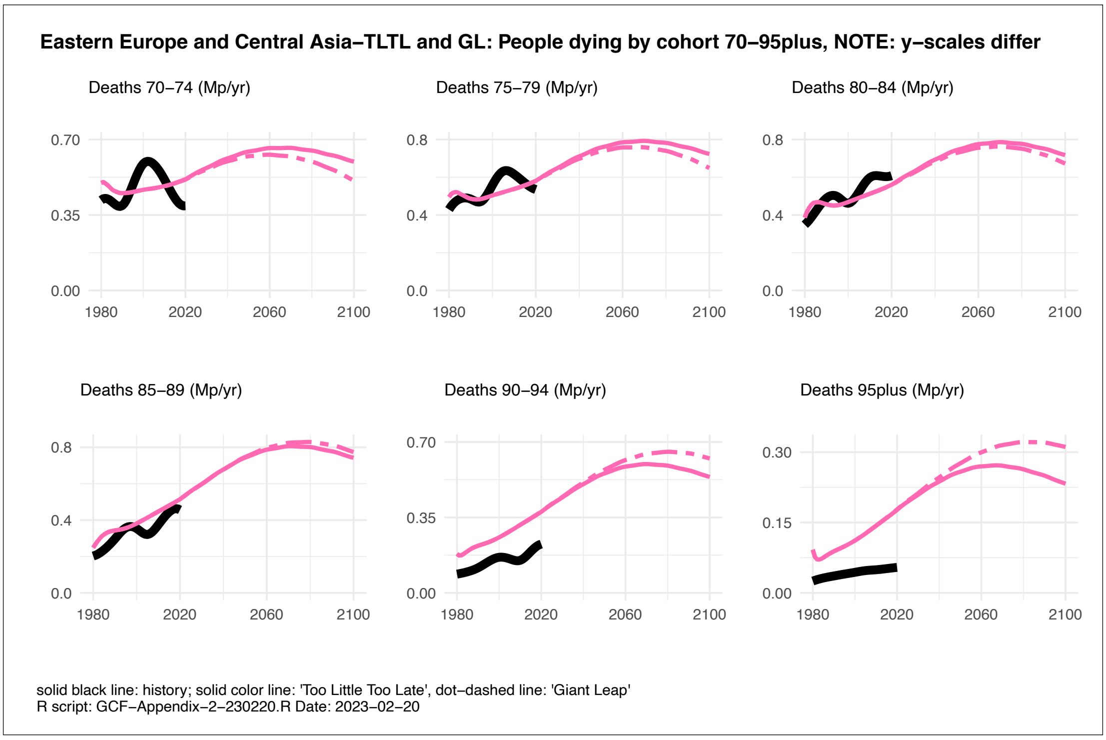


solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

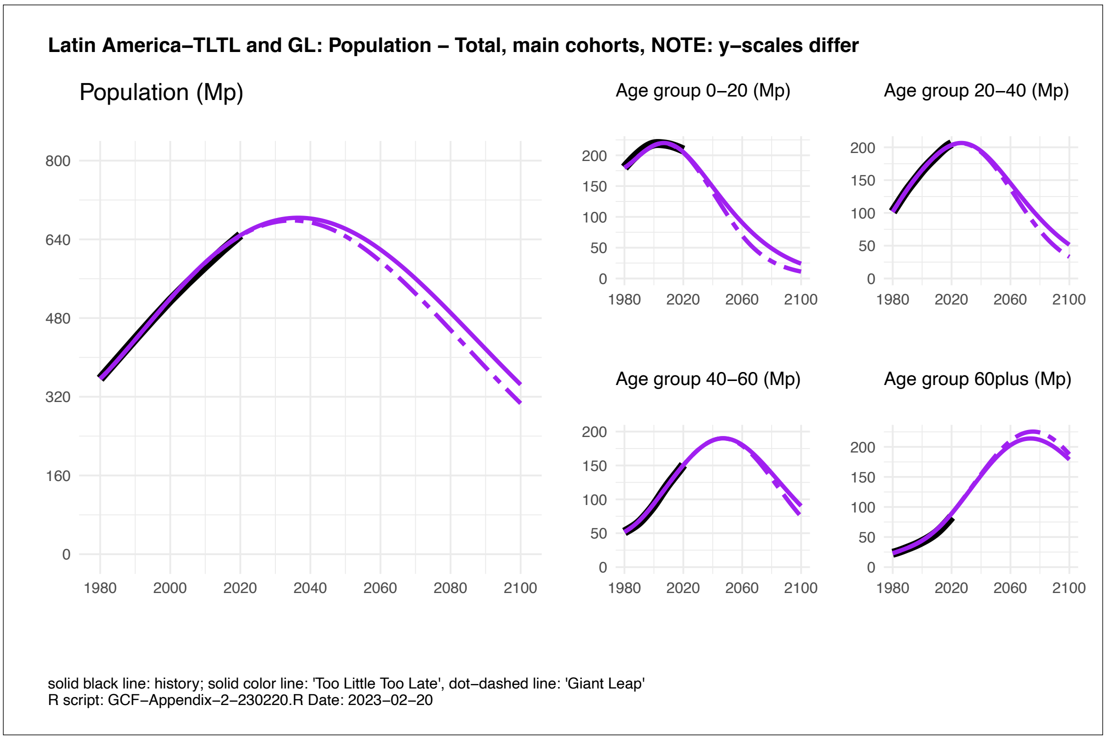
Eastern Europe and Central Asia–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ

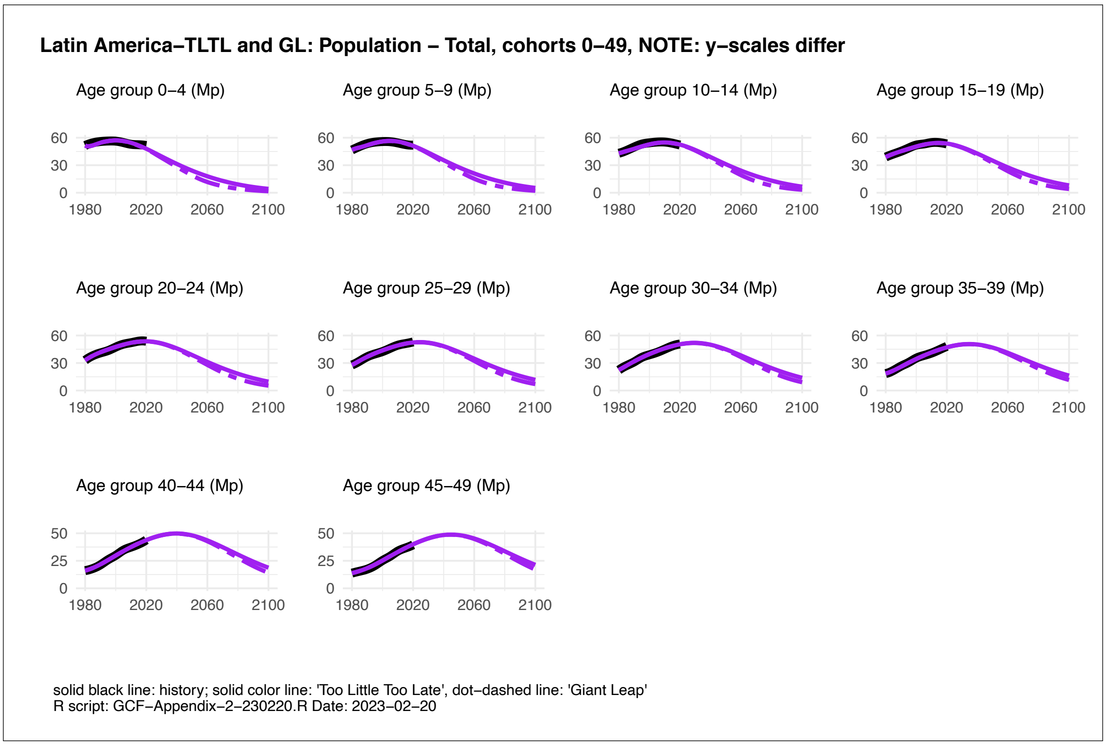


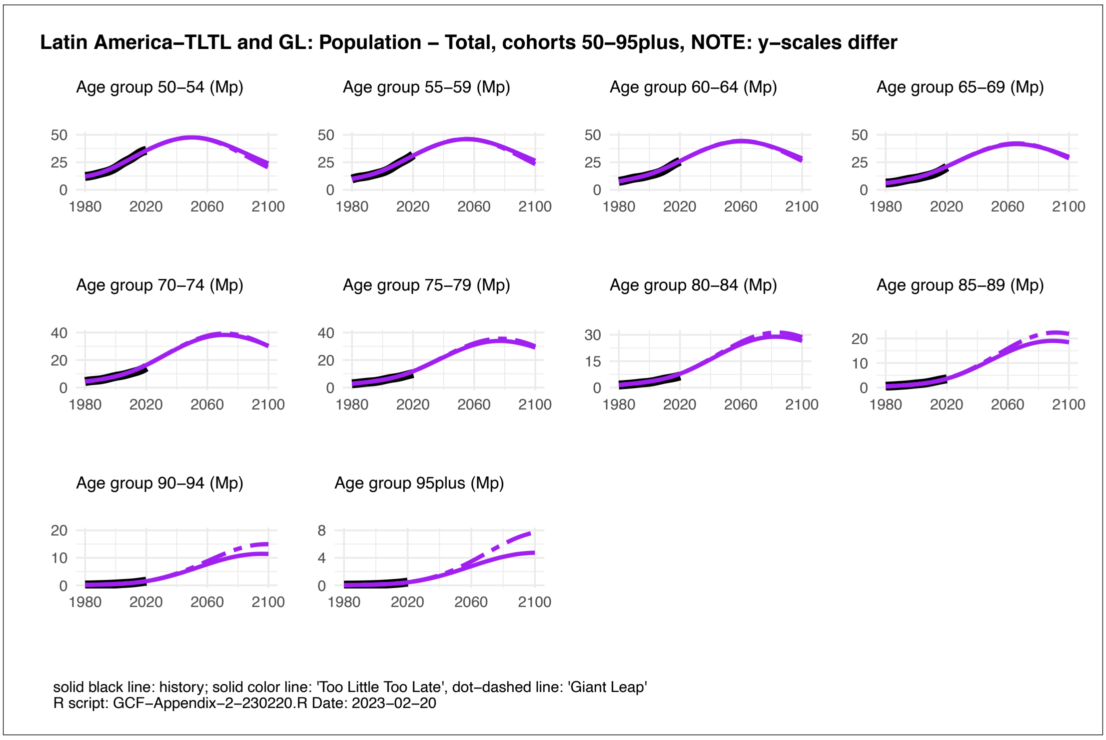
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

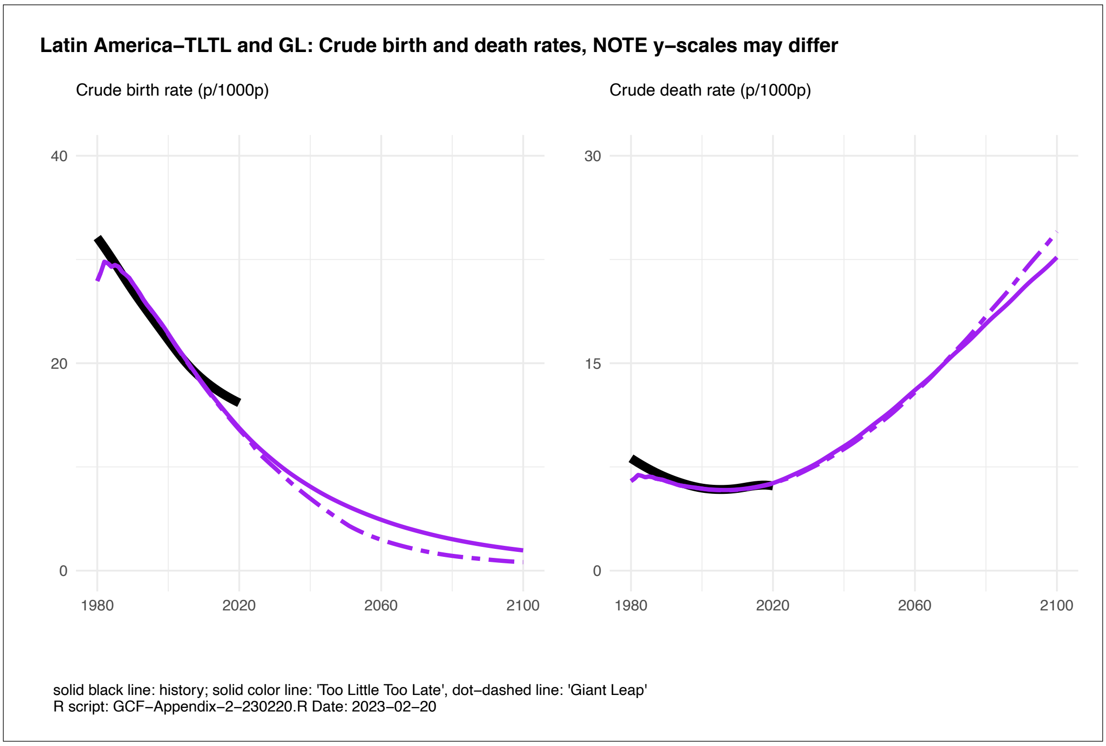

Eastern Europe and Central Asia–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
0.70
0.35
0.00
0.8
0.4
0.0
0.30
0.15
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

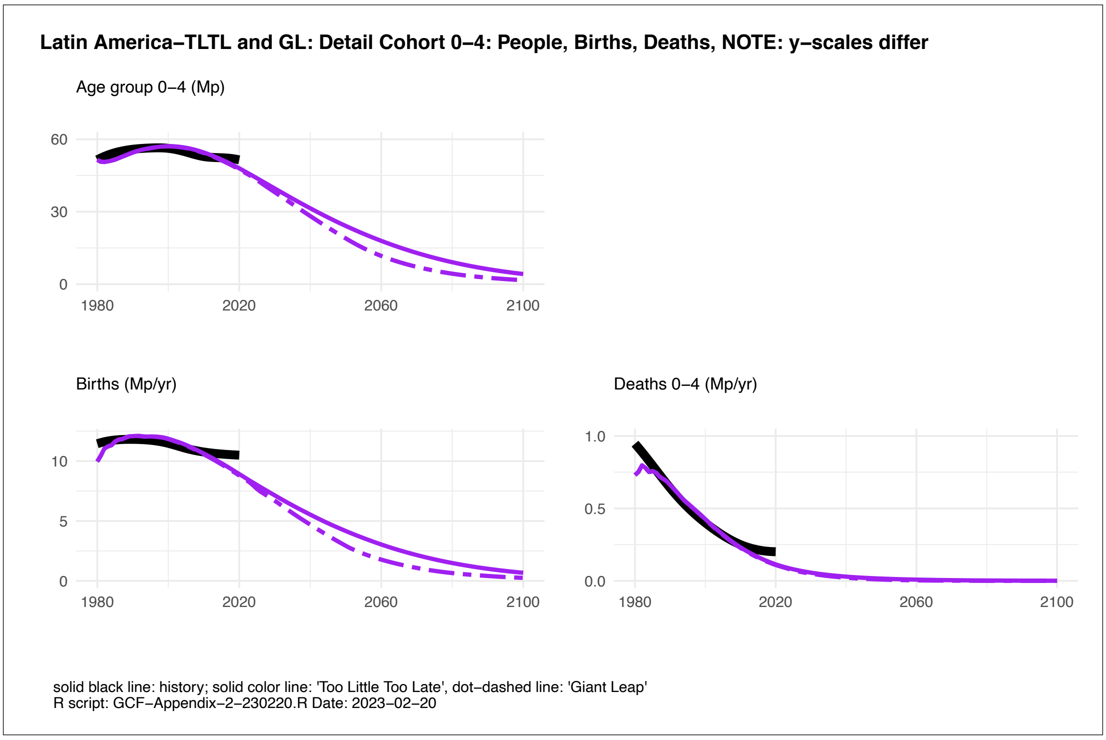
Regional Data E4A – Latin America demographics 1980–2100

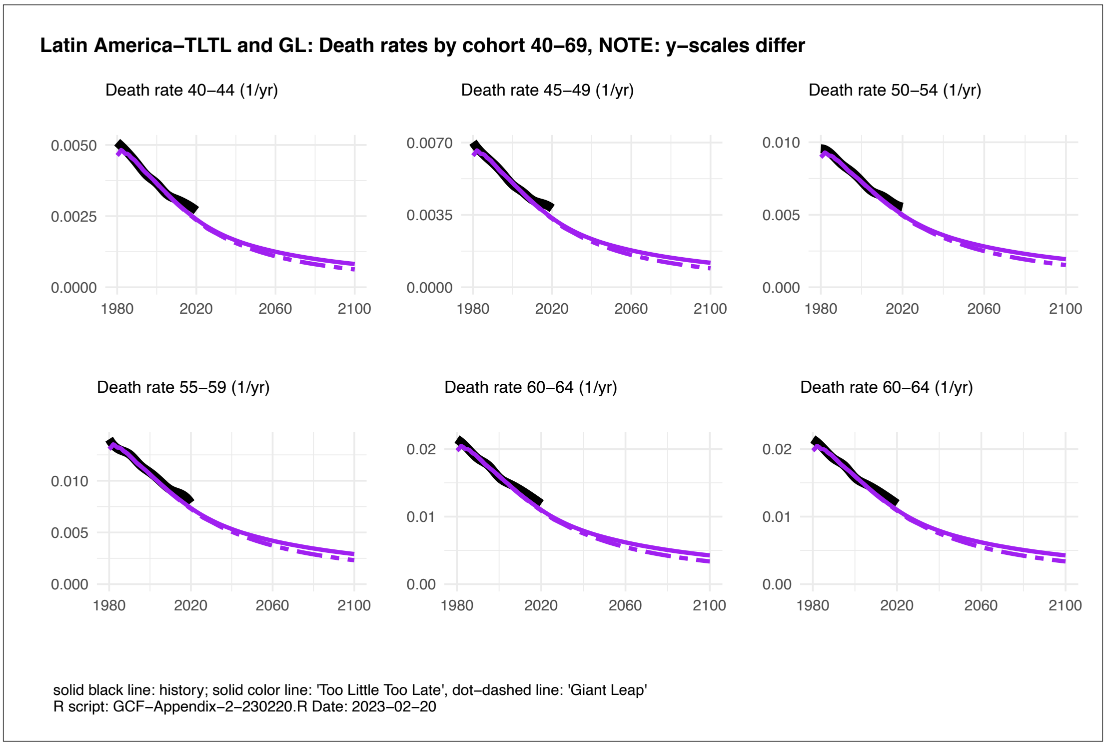


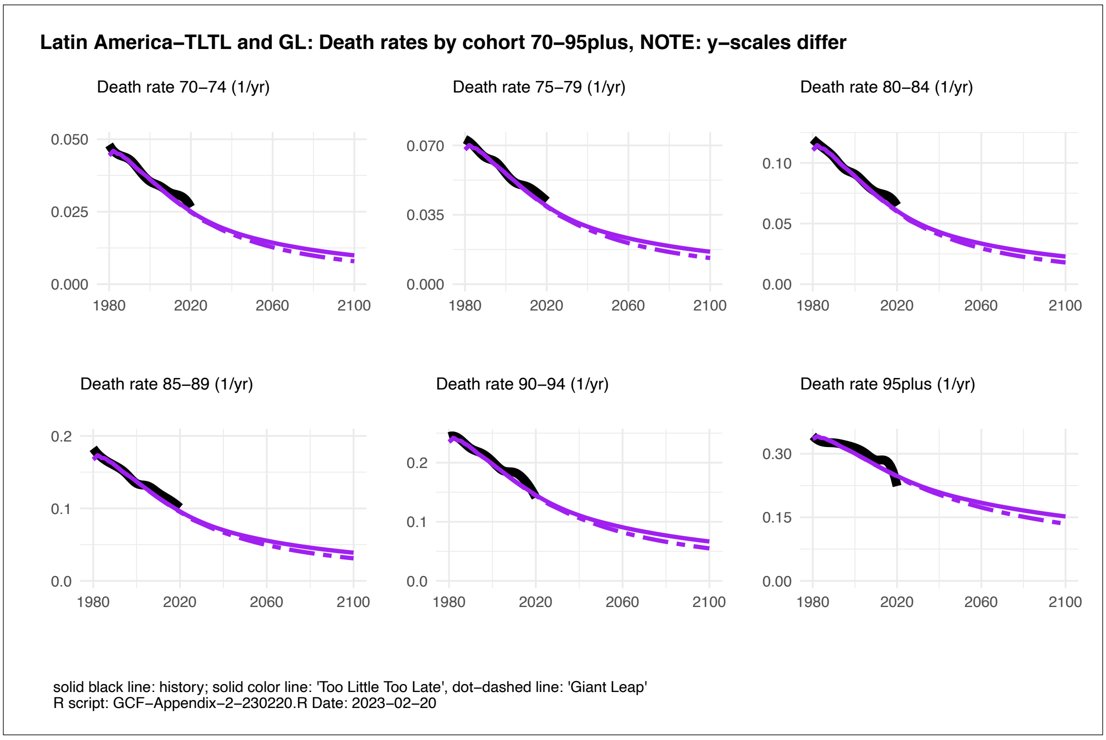



Latin America–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

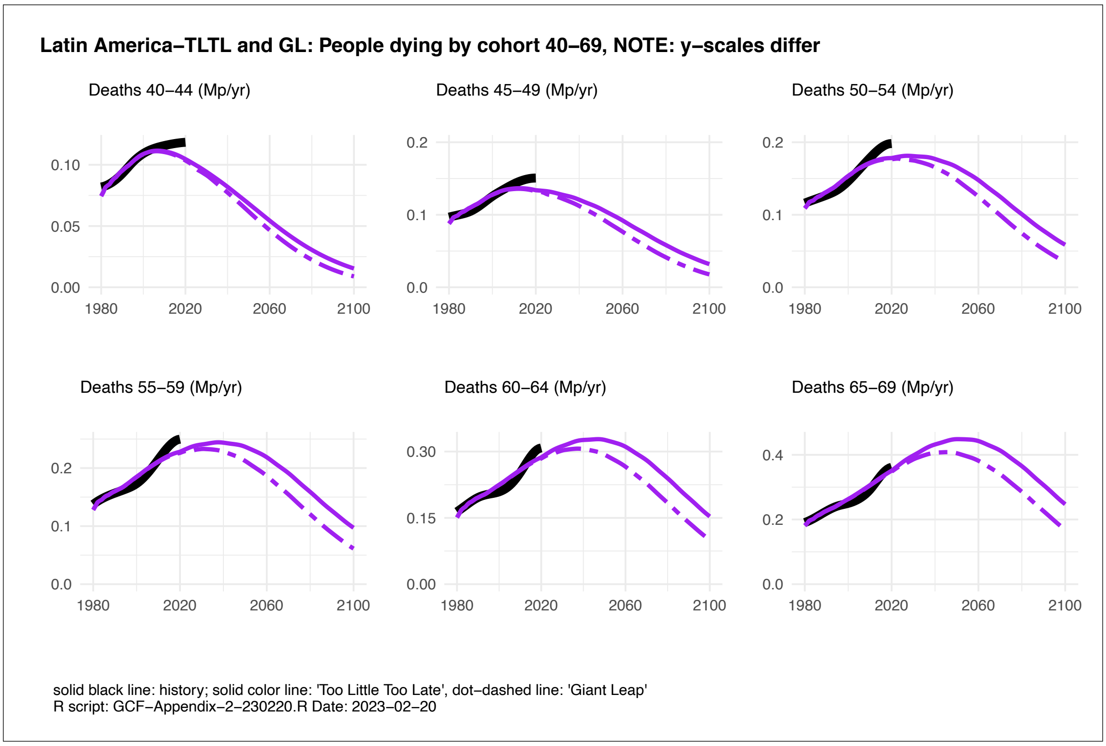

Latin America–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
40
20
0
30
15
0
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Latin America–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
Births (Mp/yr)
Deaths 0–4 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

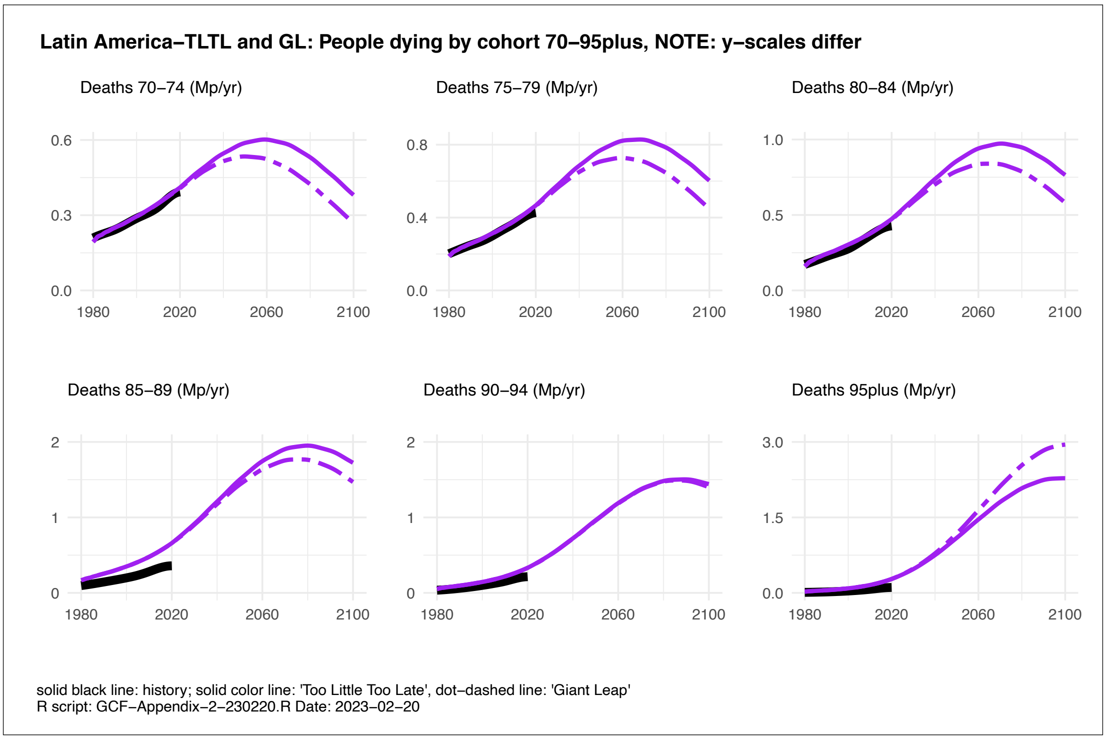

Latin America–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
Death rate 45–49 (1/yr)
Death rate 50–54 (1/yr)
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
Death rate 60–64 (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20



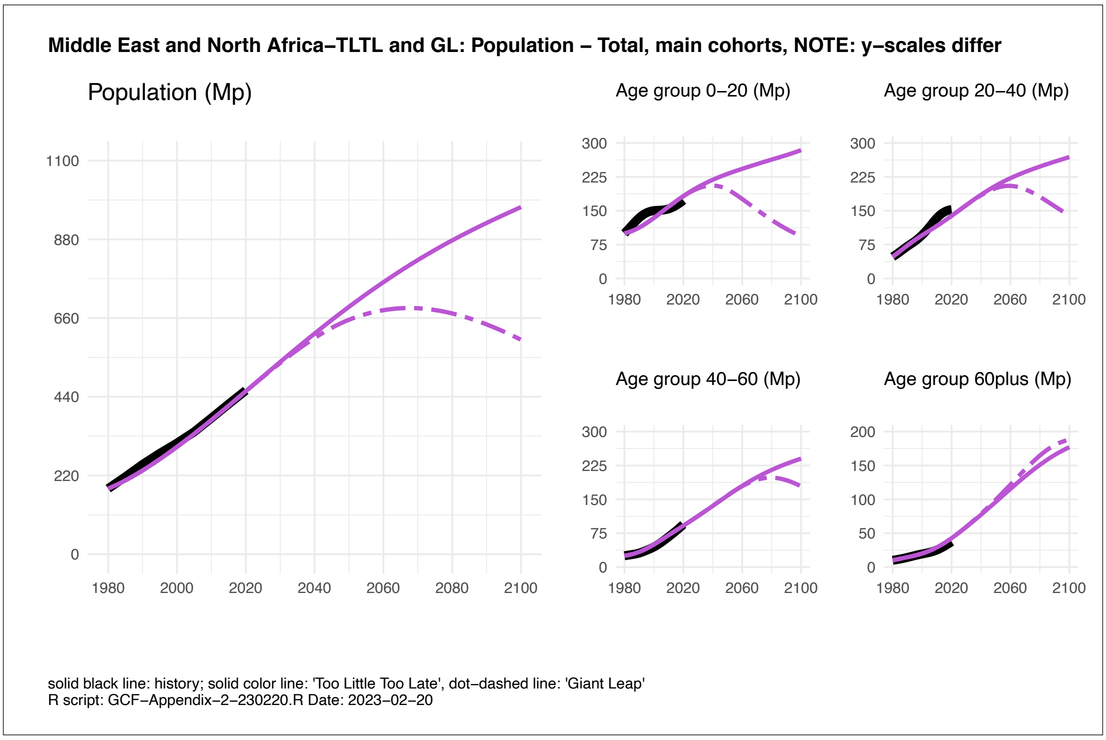
Latin America–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

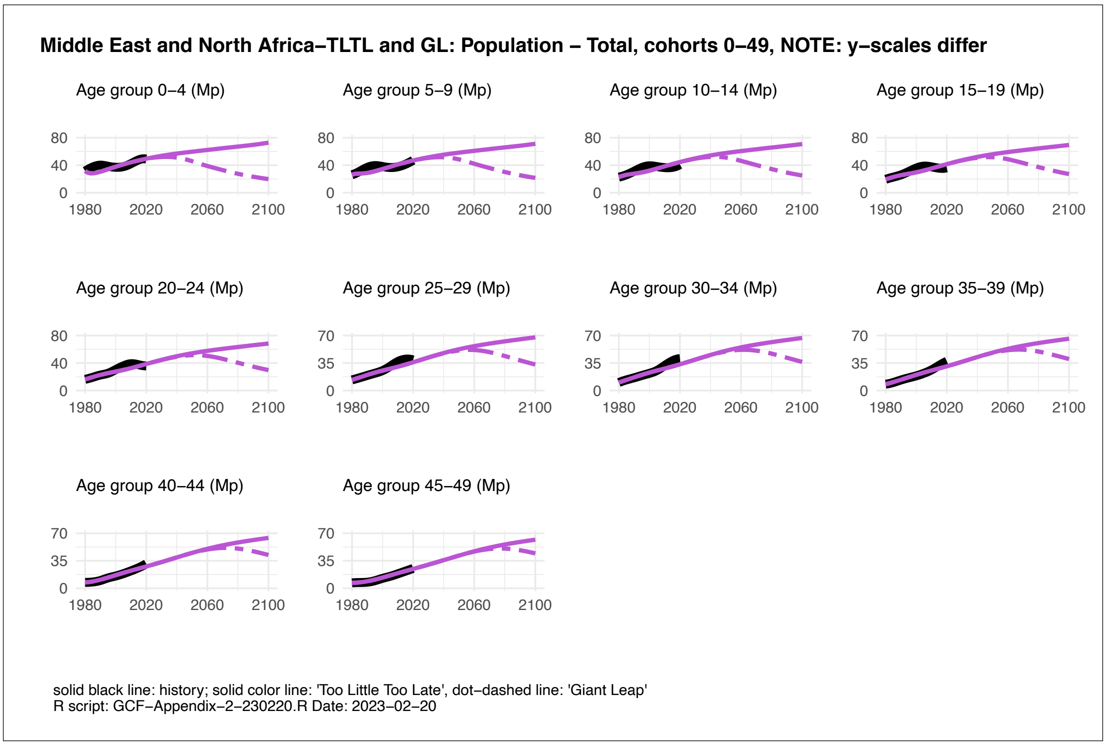


Latin America–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

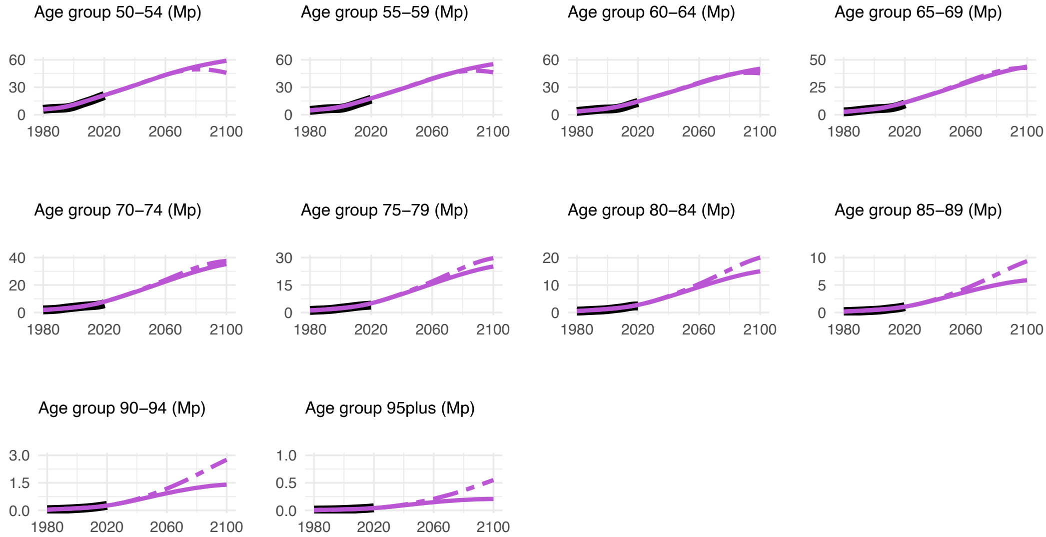

Latin America–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Regional Data E4A – Middle East and North Africa demographics 1980–2100



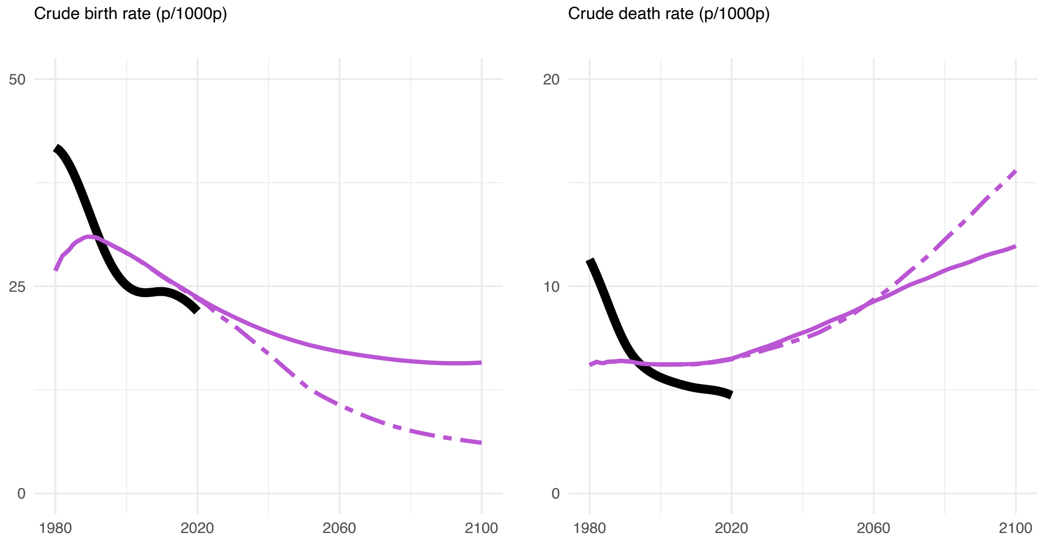


Middle East and North Africa–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ



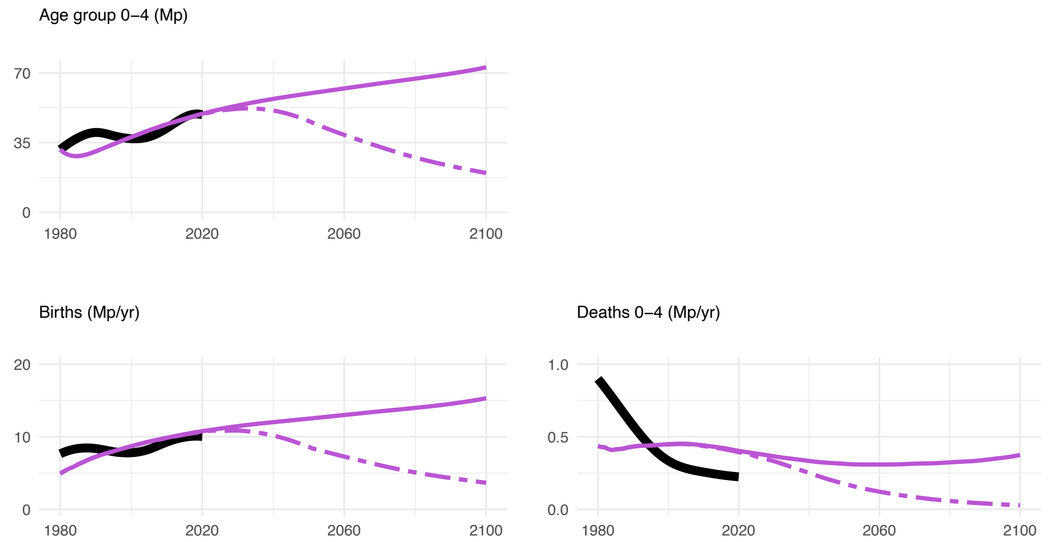
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Middle East and North Africa–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ



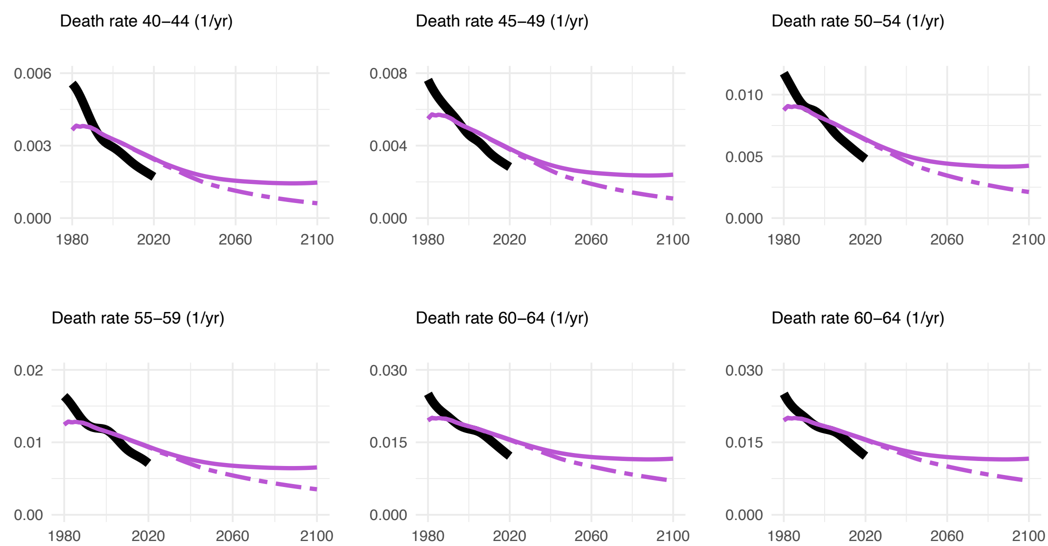
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Middle East and North Africa–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ

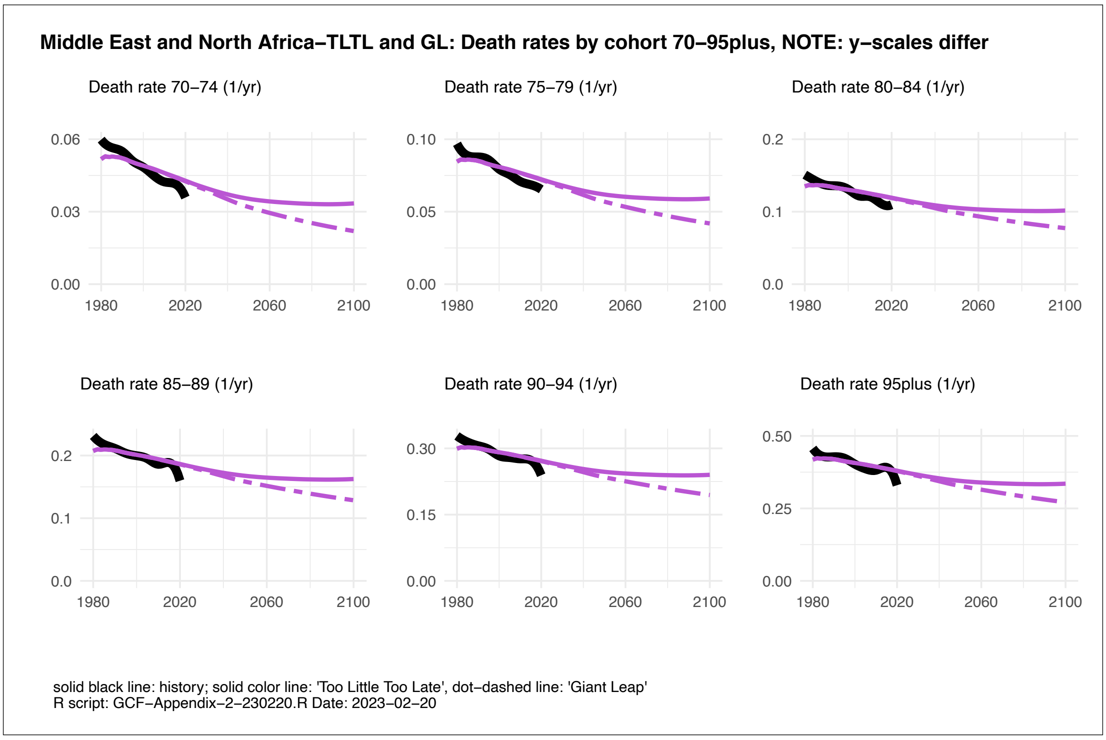


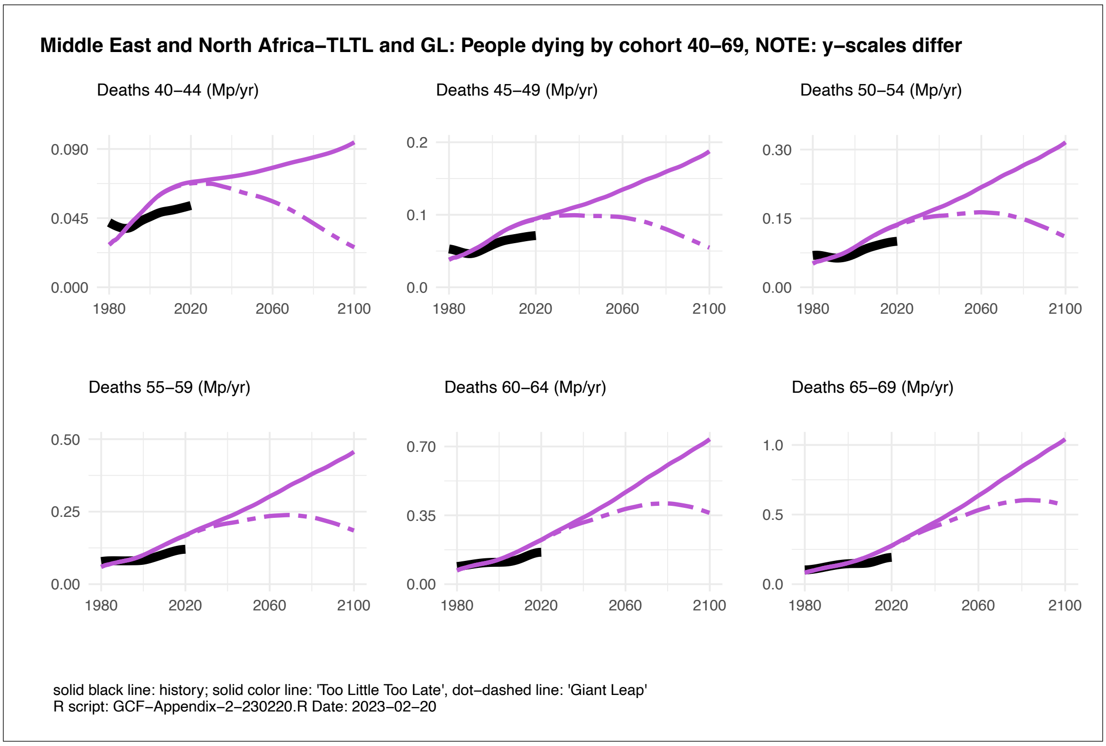
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

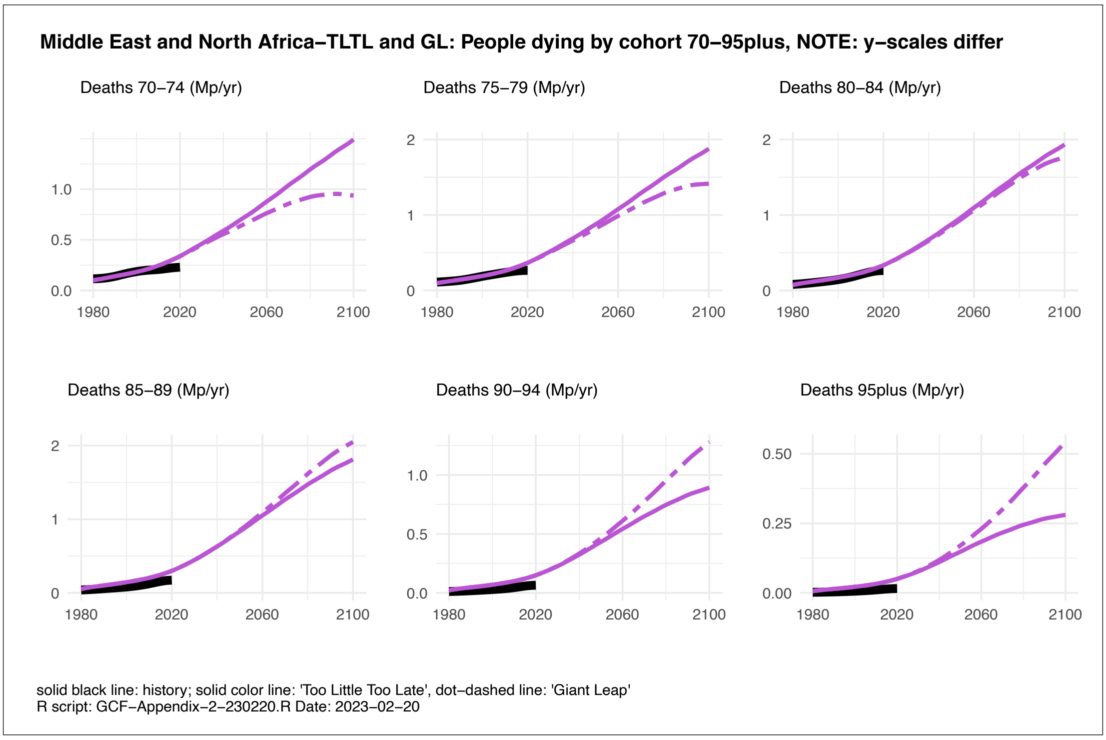
Middle East and North Africa–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ



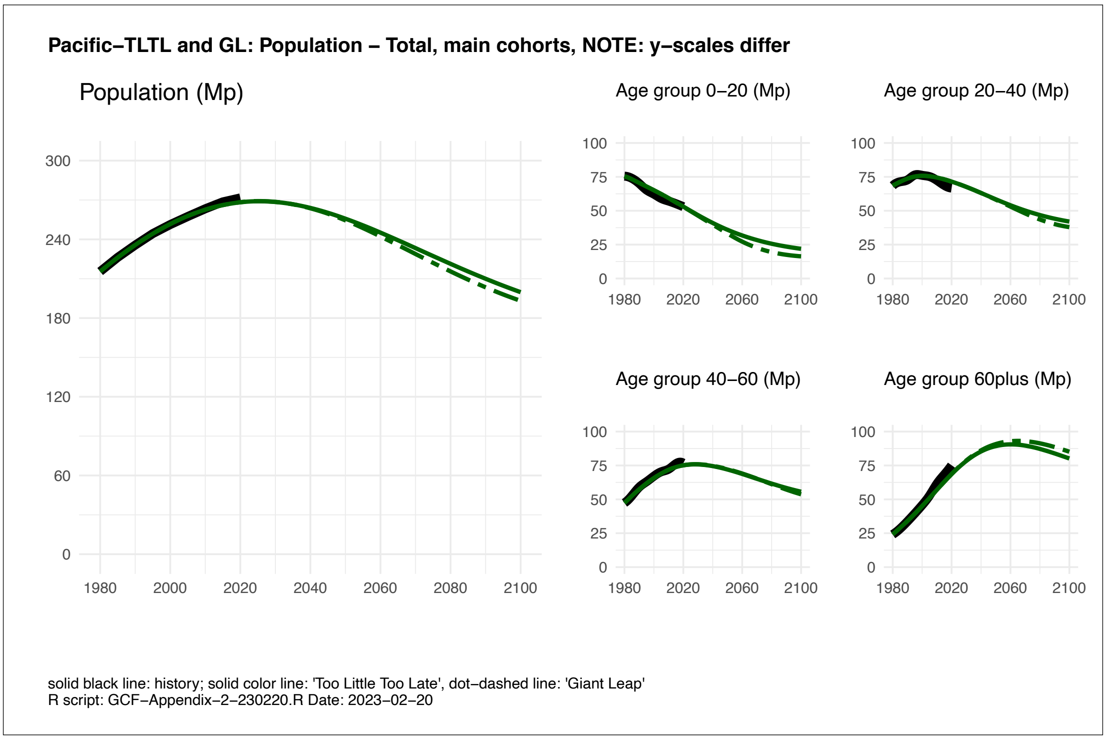
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

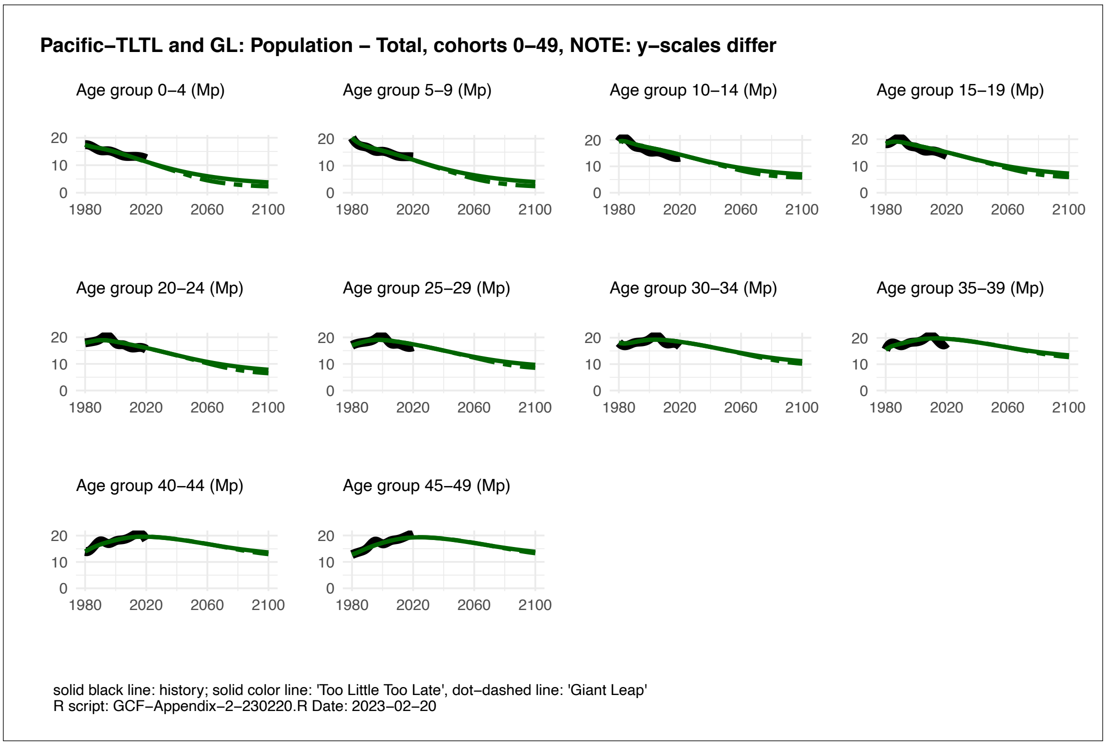

Middle East and North Africa–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

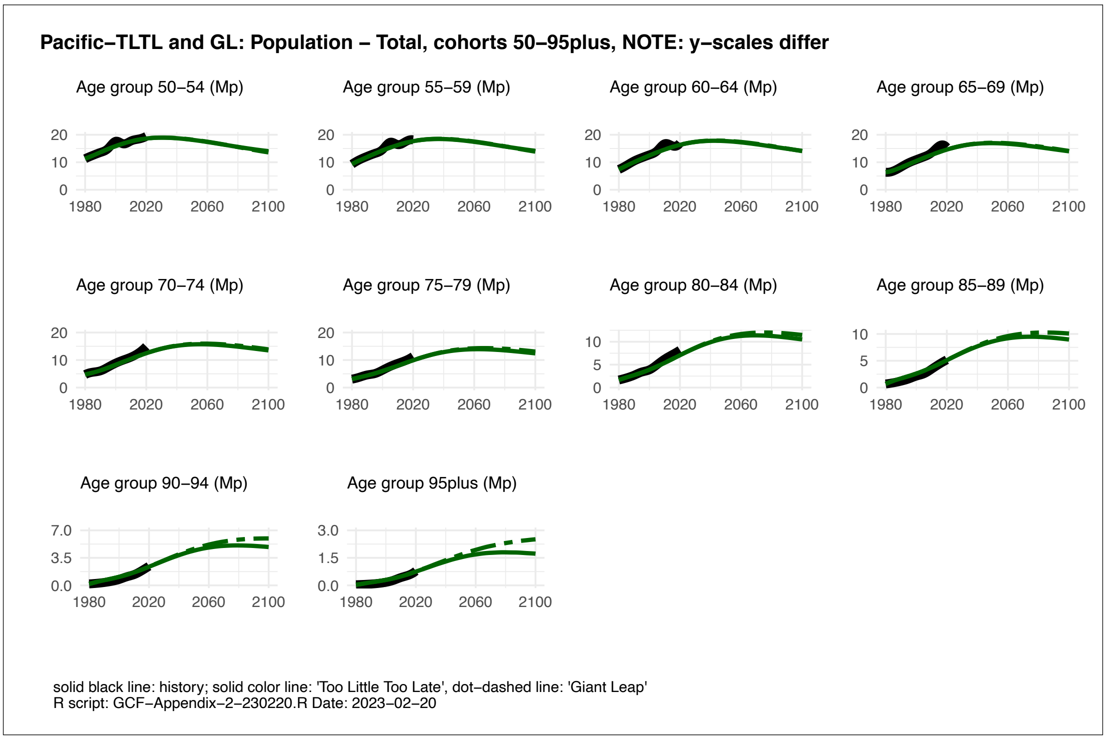

Middle East and North Africa–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

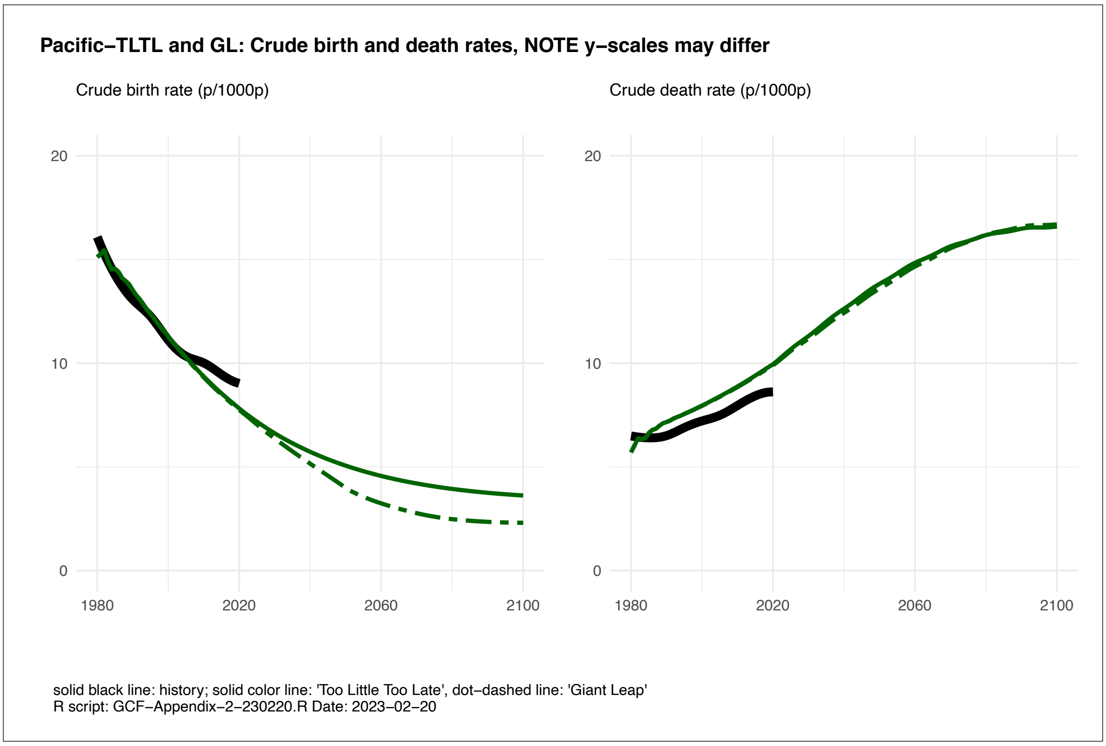

Middle East and North Africa–TLTL and GL: People dying by cohort 70–95plus, NOTE: y-scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

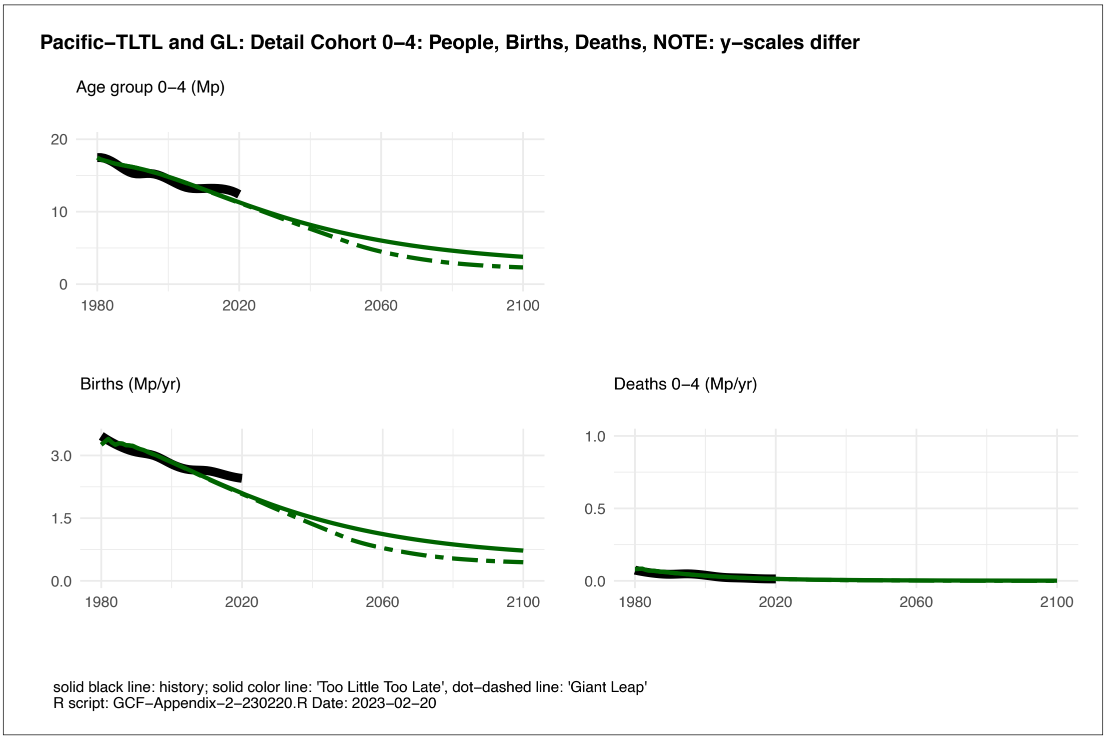
Regional Data E4A – Pacific Asia demographics 1980–2100

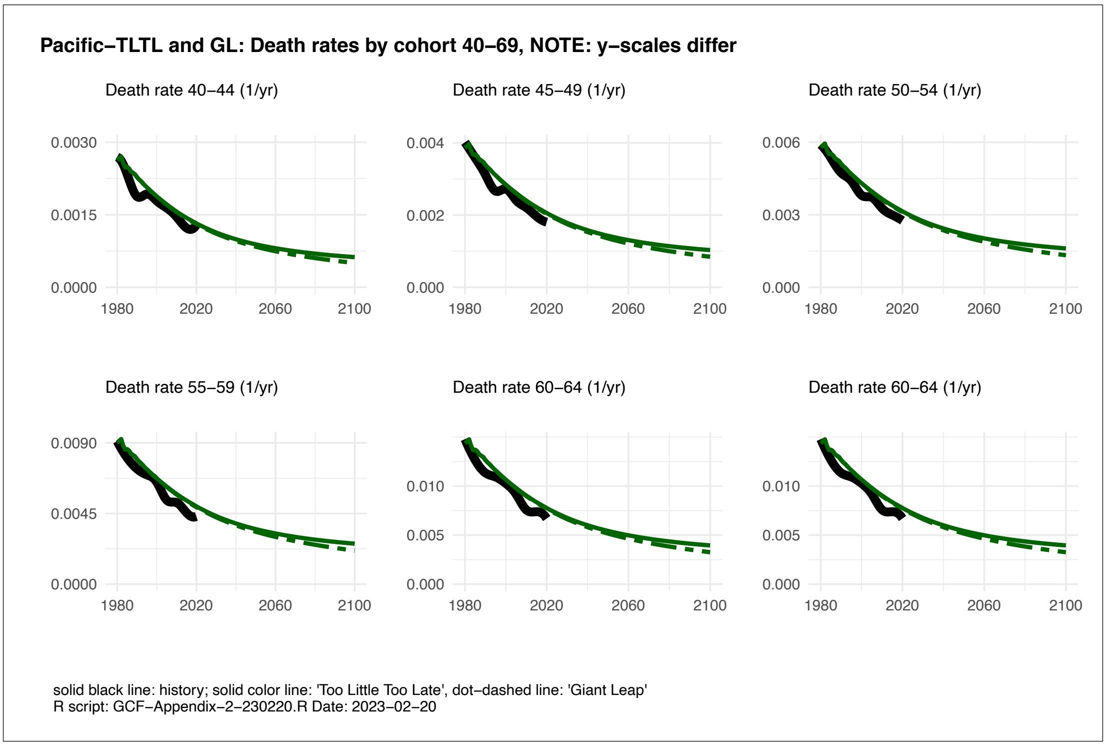


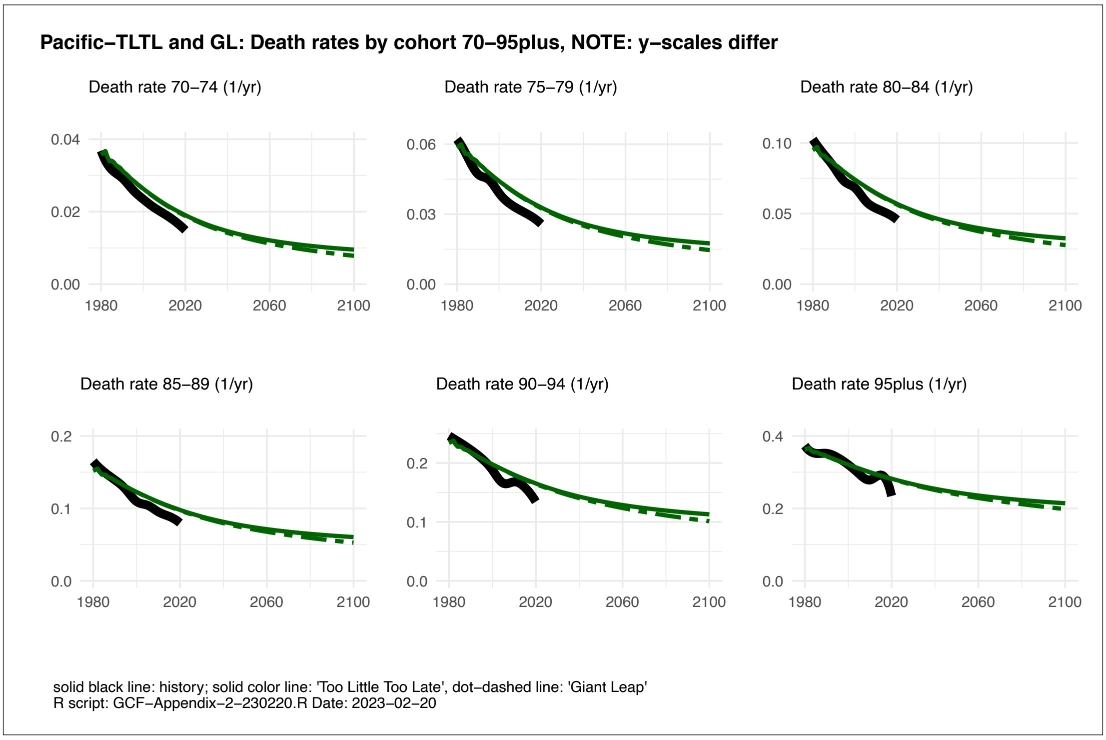


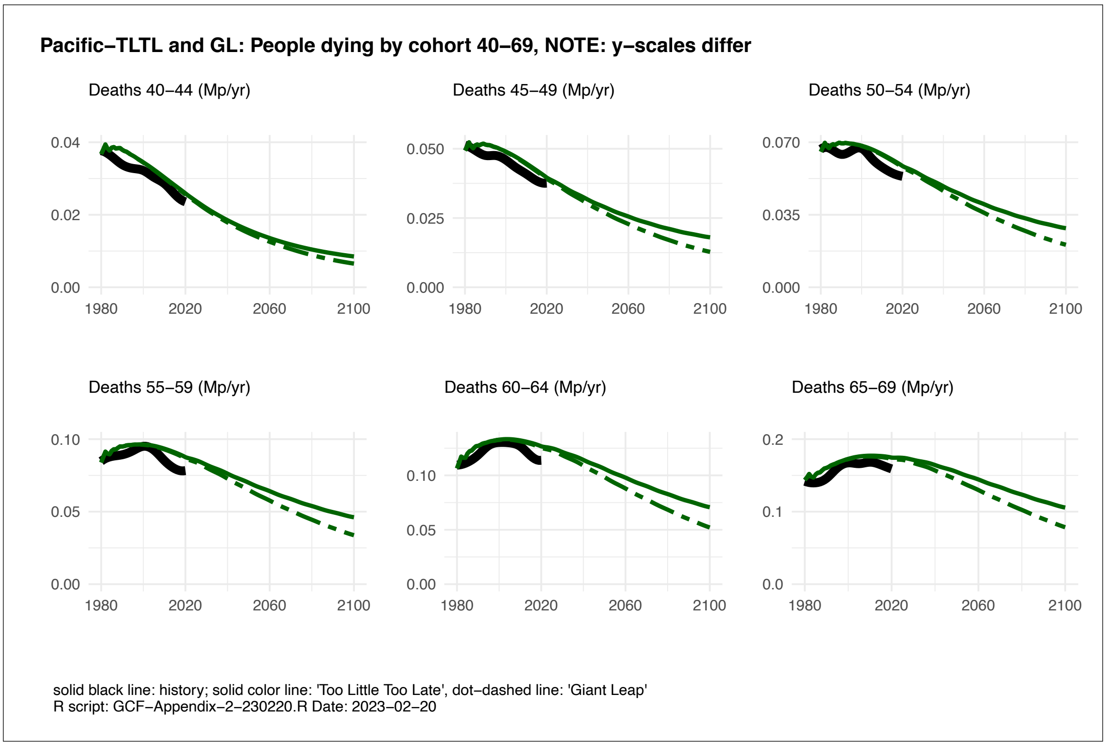

Pacific–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

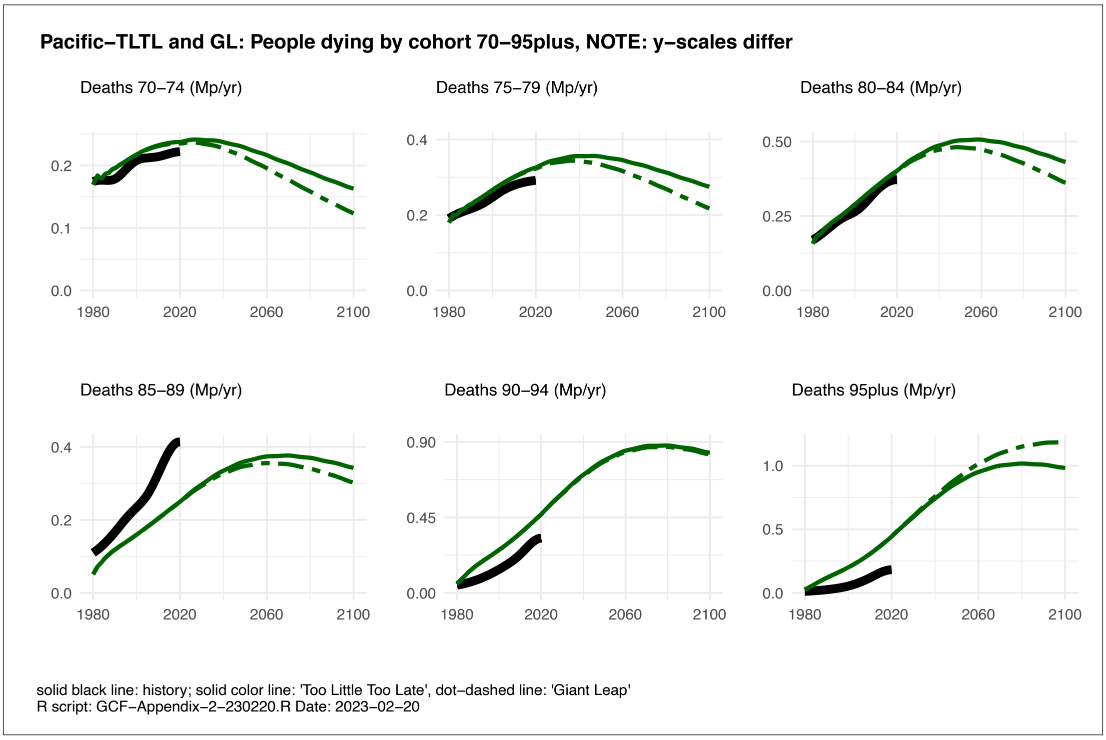

Pacific–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
20
10
0
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Pacific–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
Births (Mp/yr)
Deaths 0–4 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

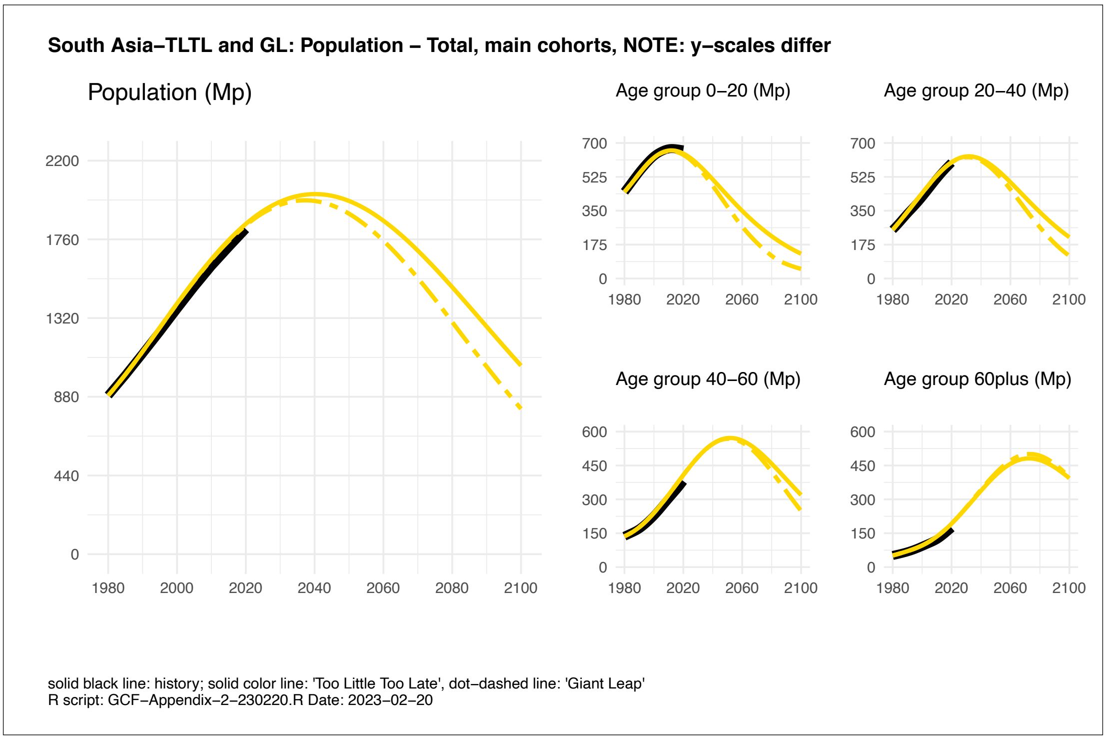

Pacific–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
Death rate 45–49 (1/yr)
Death rate 50–54 (1/yr)
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
Death rate 60–64 (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

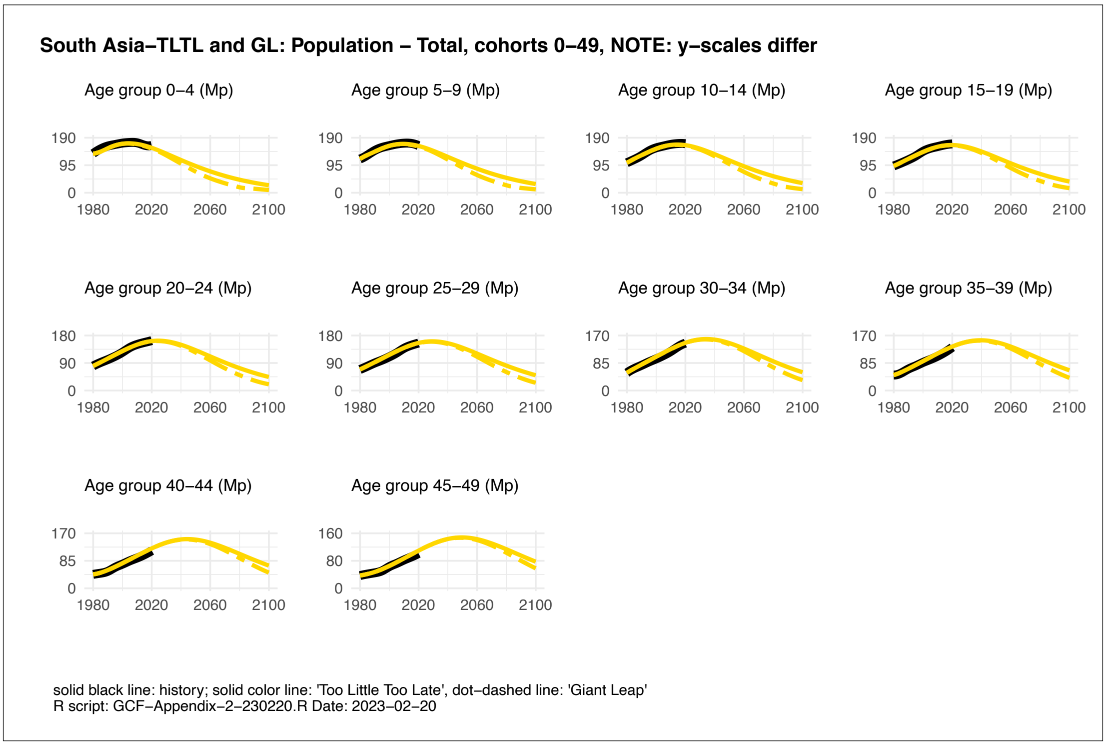

Pacific–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y-scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

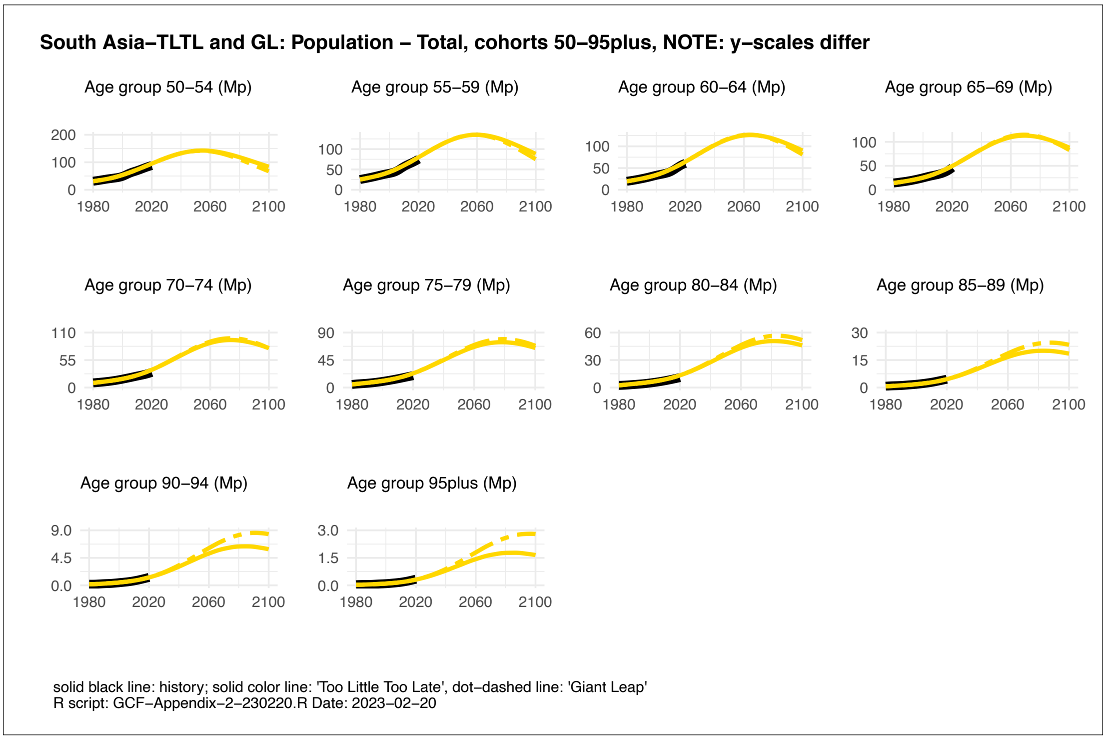

Pacific–TLTL and GL: People dying by cohort 40–69, NOTE: y-scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

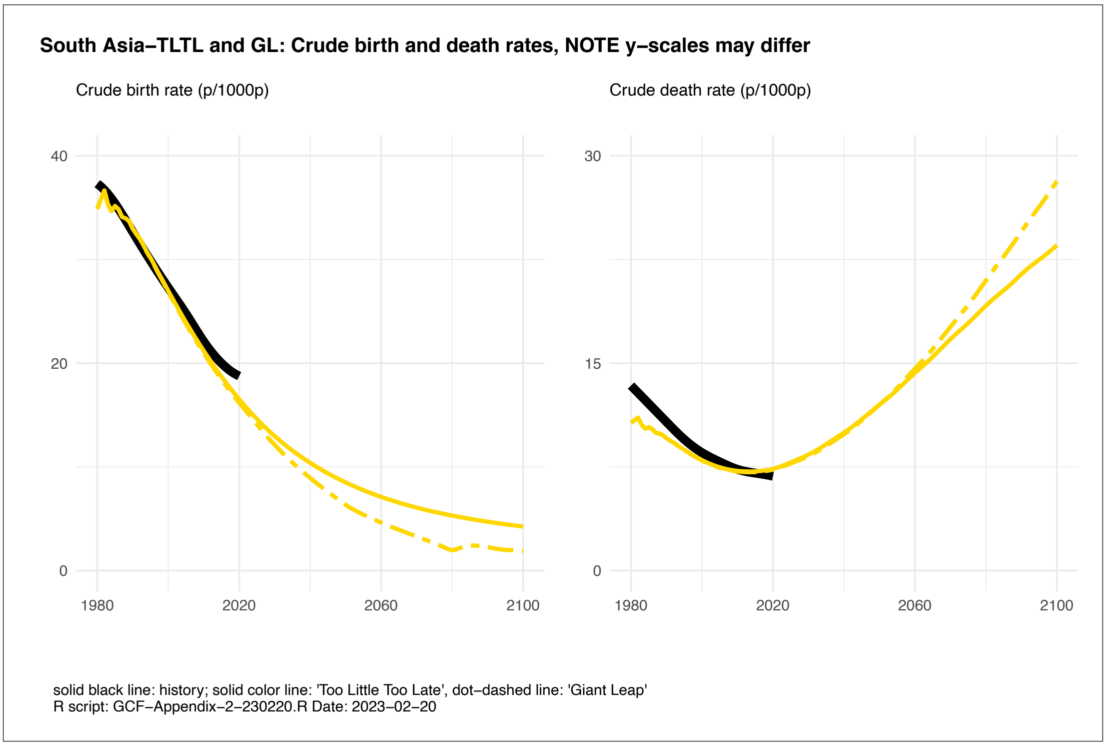

Pacific–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

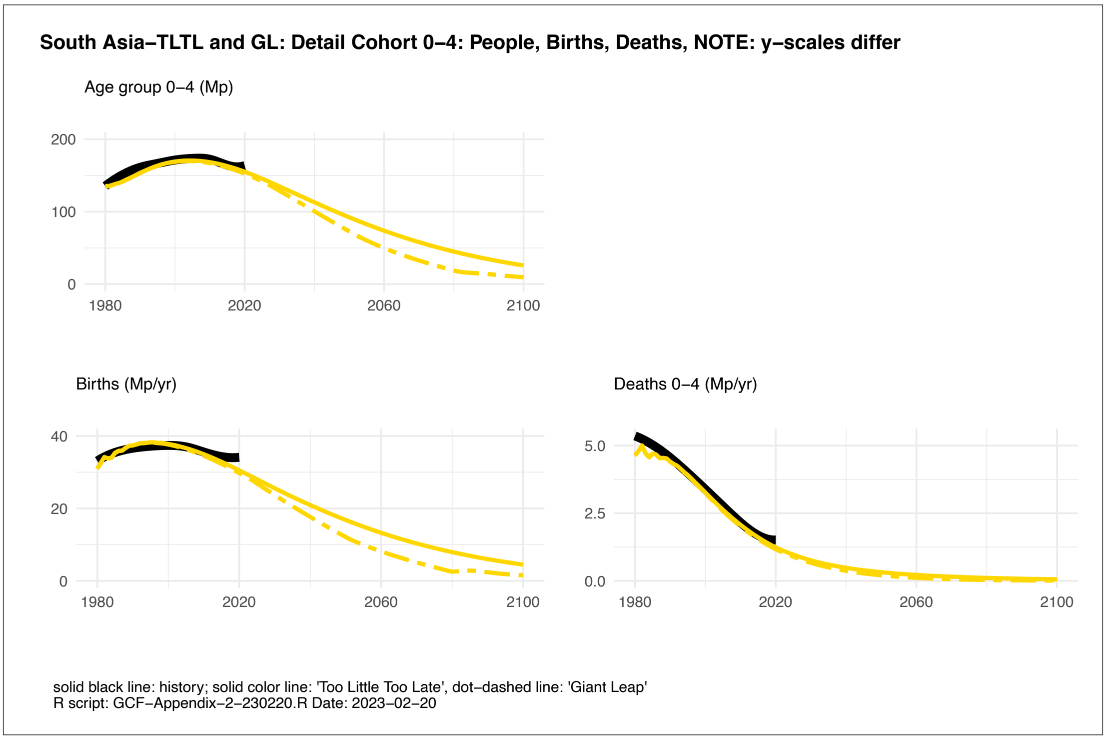
Regional Data E4A – South Asia demographics 1980–2100

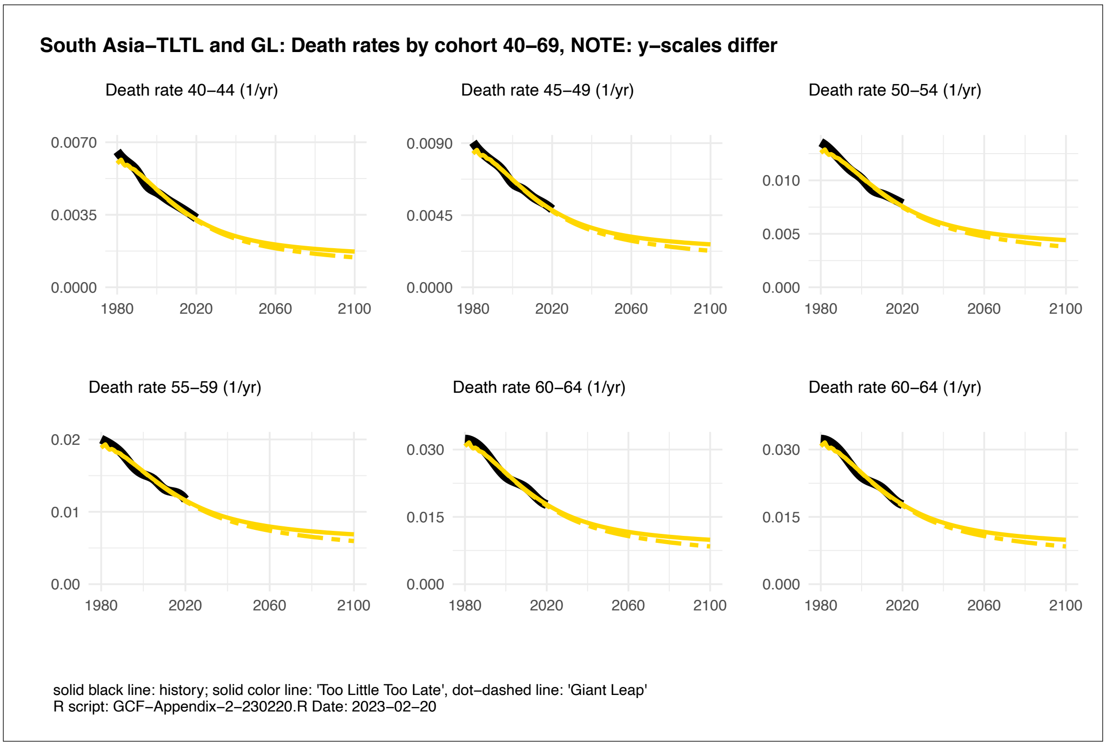


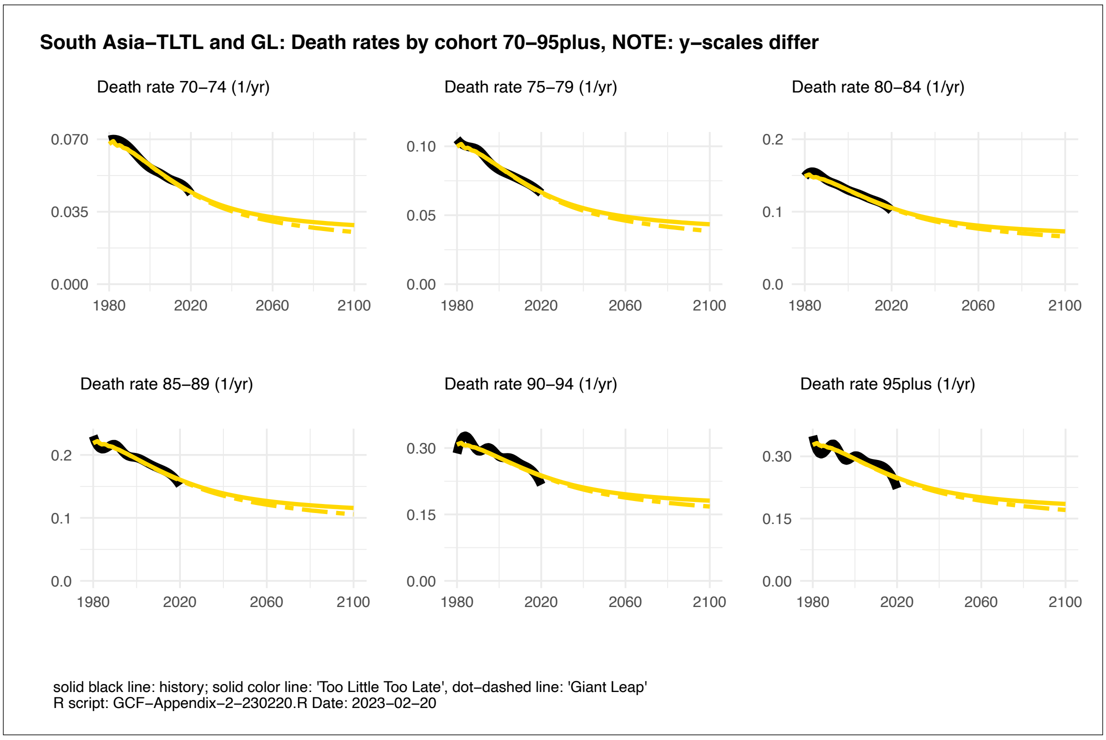


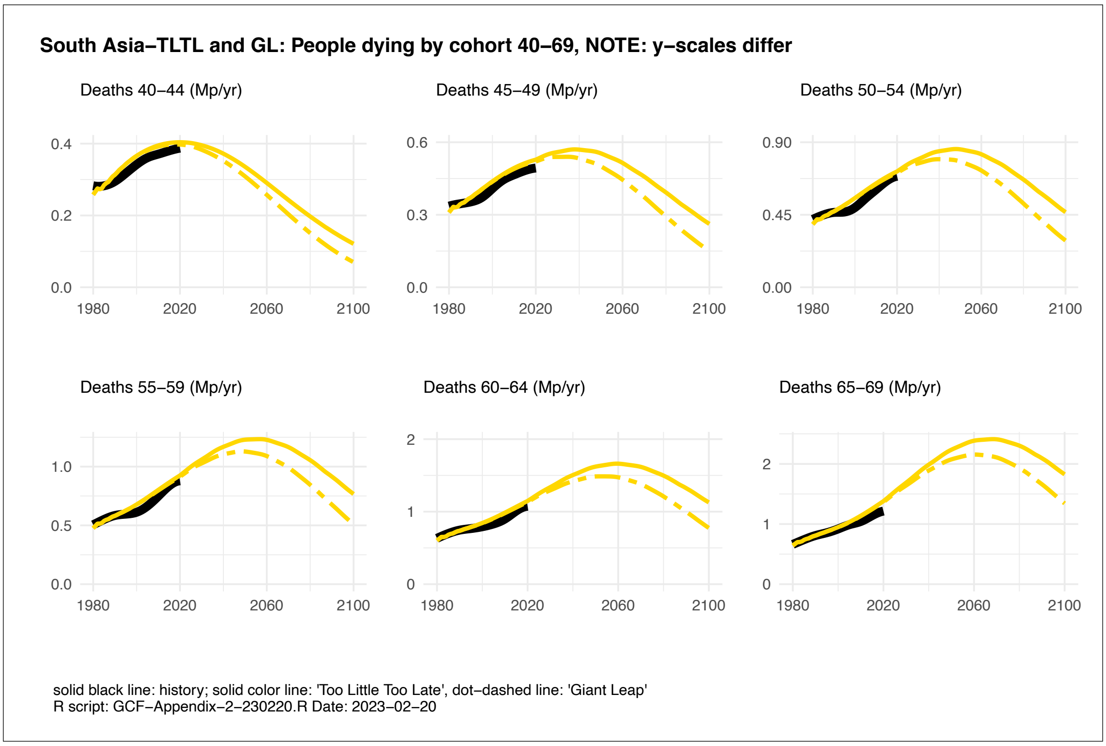

South Asia–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

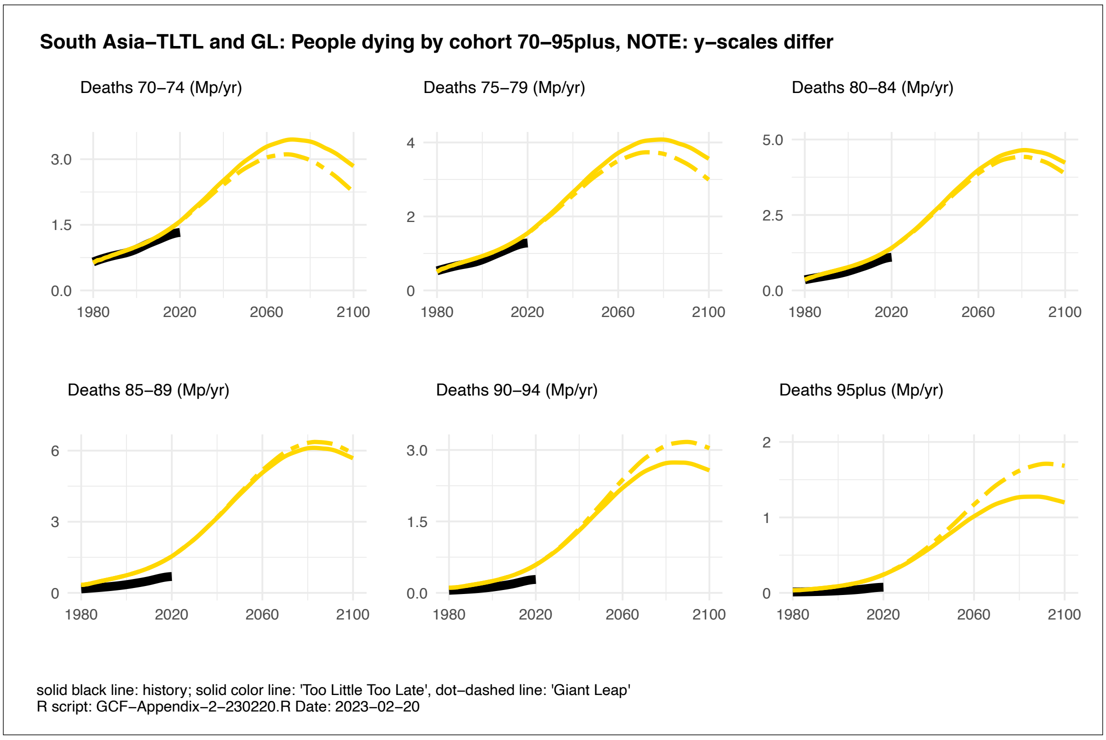

South Asia–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
40
20
0
30
15
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


South Asia–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
200
100
0
1980
2020
2060
2100
Births (Mp/yr)
40
20
0
Deaths 0–4 (Mp/yr)
5.0
2.5
0.0
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

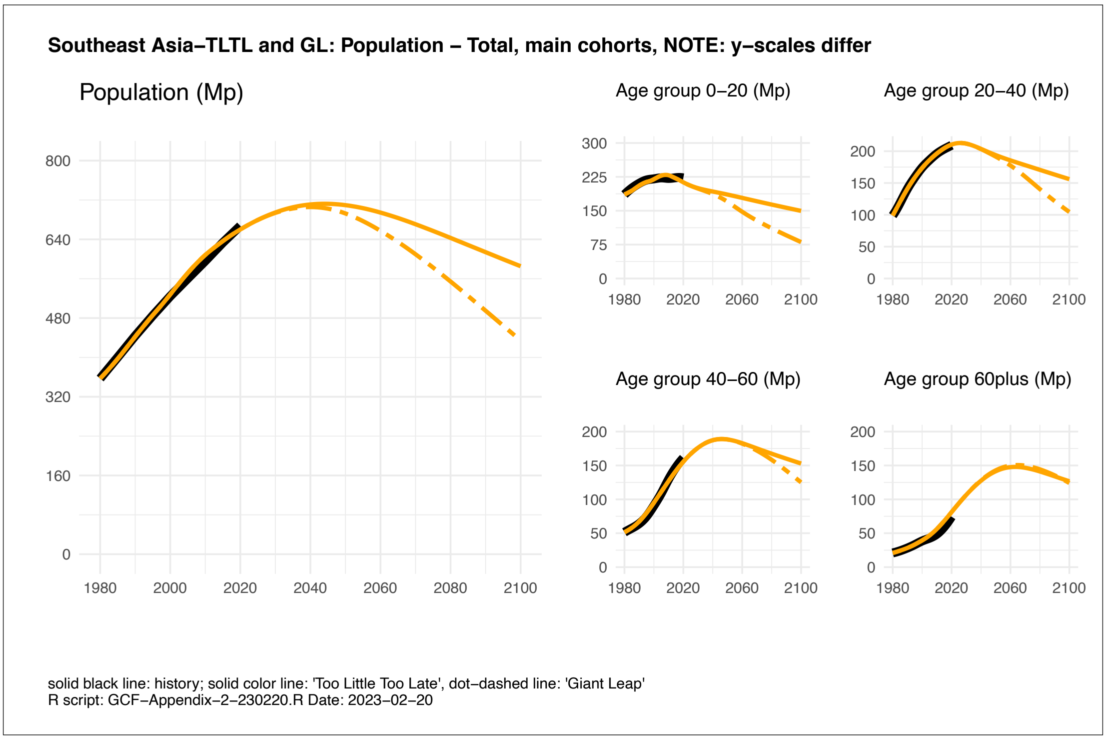

South Asia–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
0.0070
0.0035
0.0000
Death rate 45–49 (1/yr)
0.0090
0.0045
0.0000
Death rate 50–54 (1/yr)
0.010
0.005
0.000
1980
2020
2060
2100
Death rate 55–59 (1/yr)
0.02
0.01
0.00
Death rate 60–64 (1/yr)
0.030
0.015
0.000
Death rate 60–64 (1/yr)
0.030
0.015
0.000
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

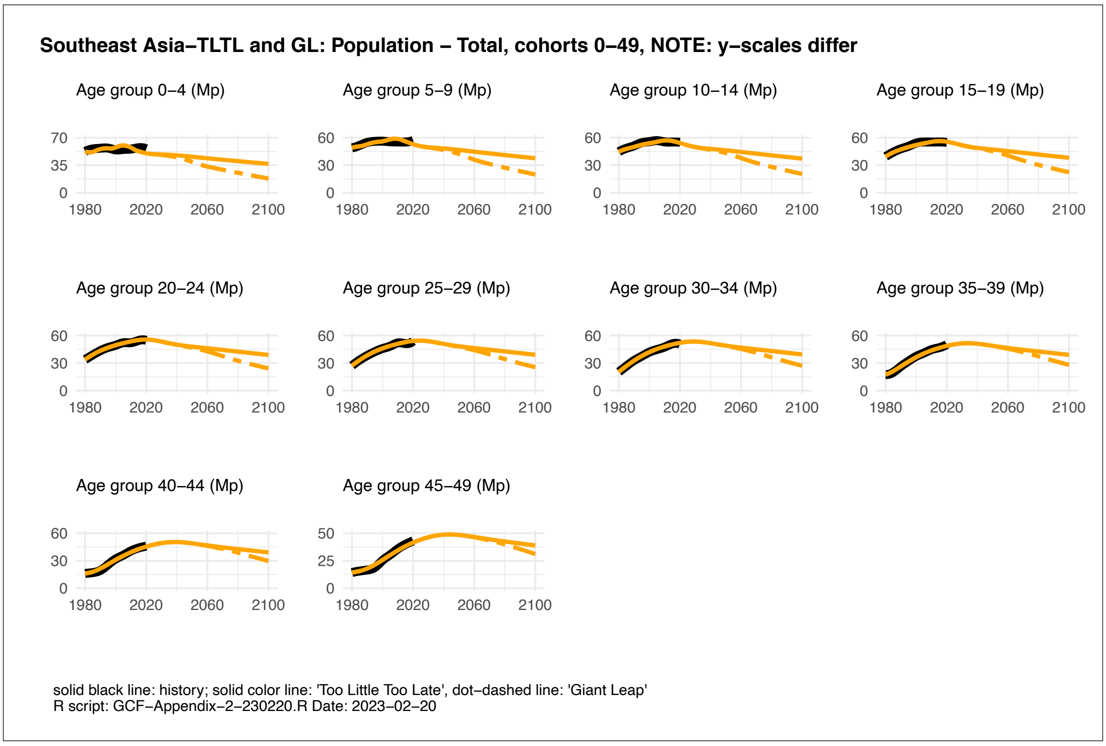

South Asia–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


South Asia–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

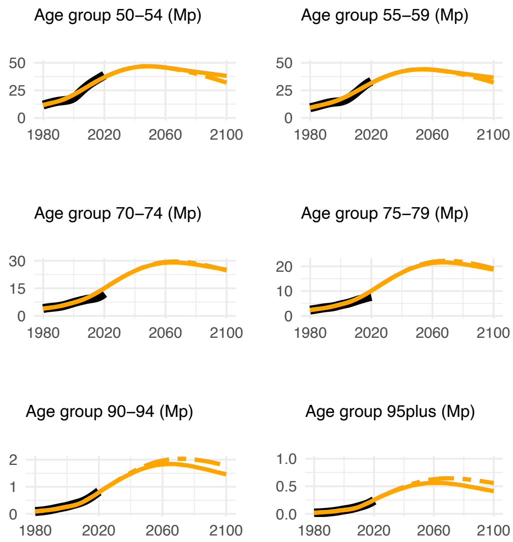

South Asia–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

Regional Data E4A – Southeast Asia demographics 1980–2100



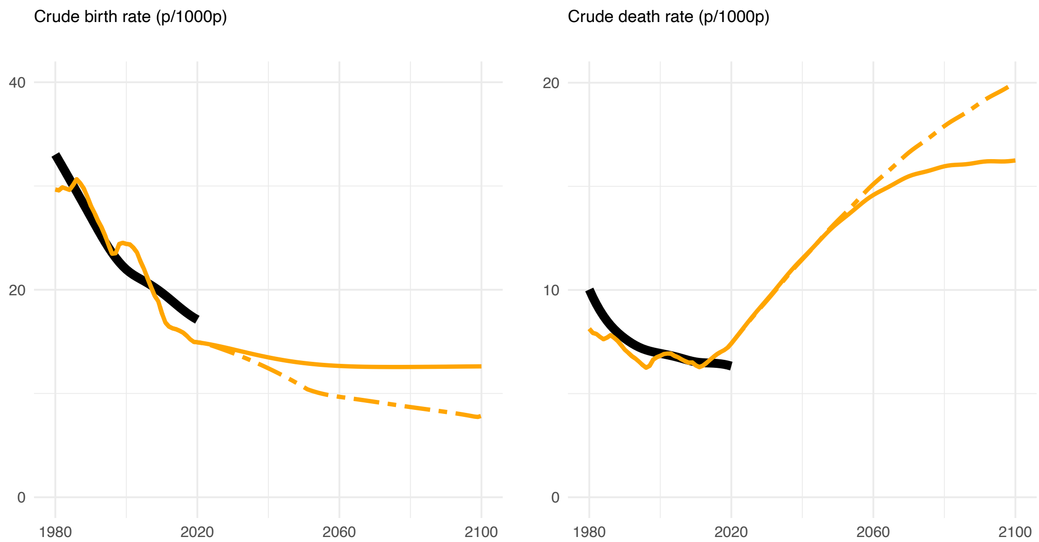


Southeast Asia–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ

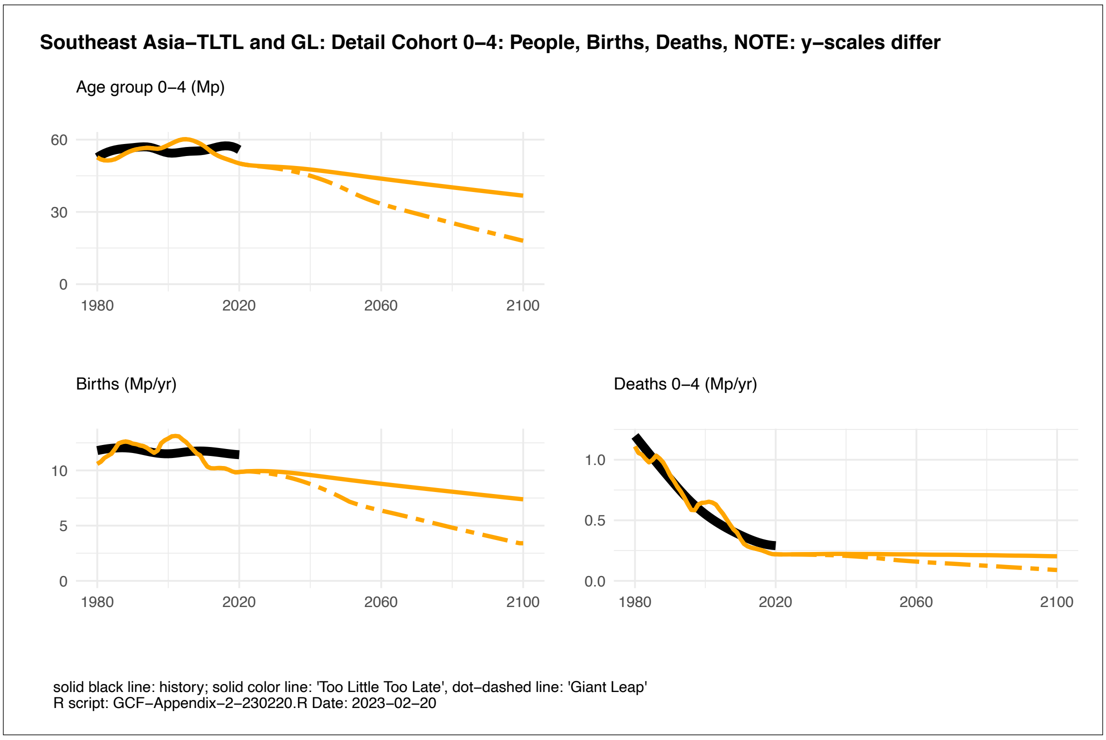


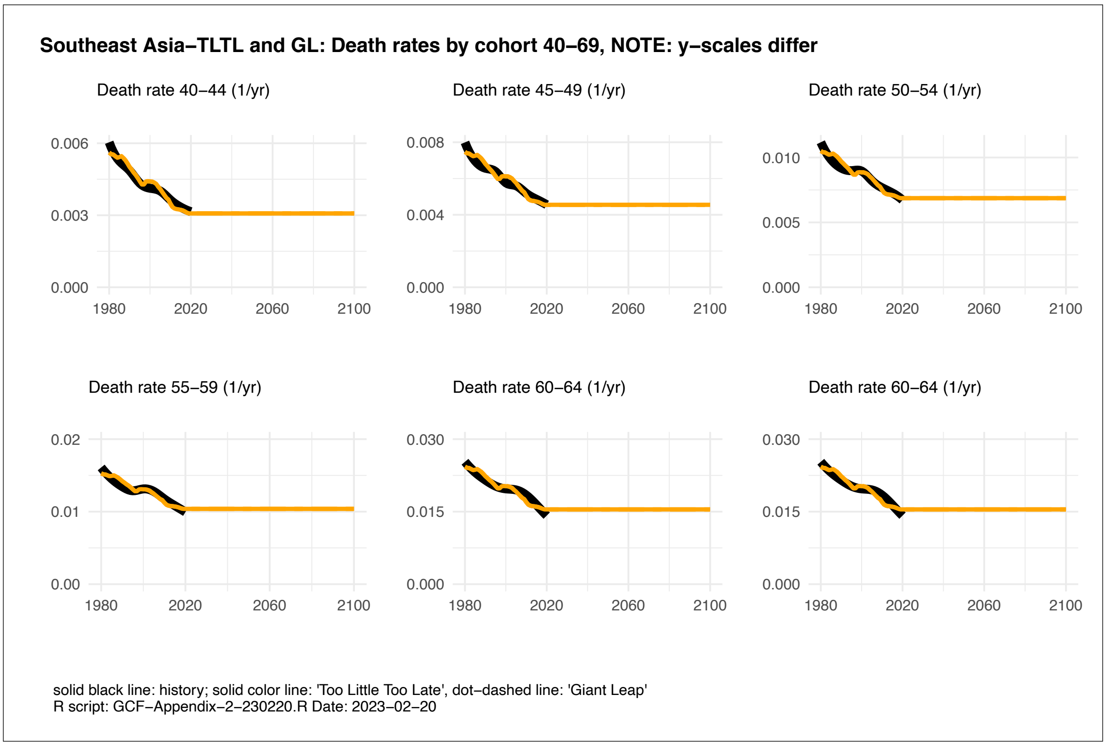
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

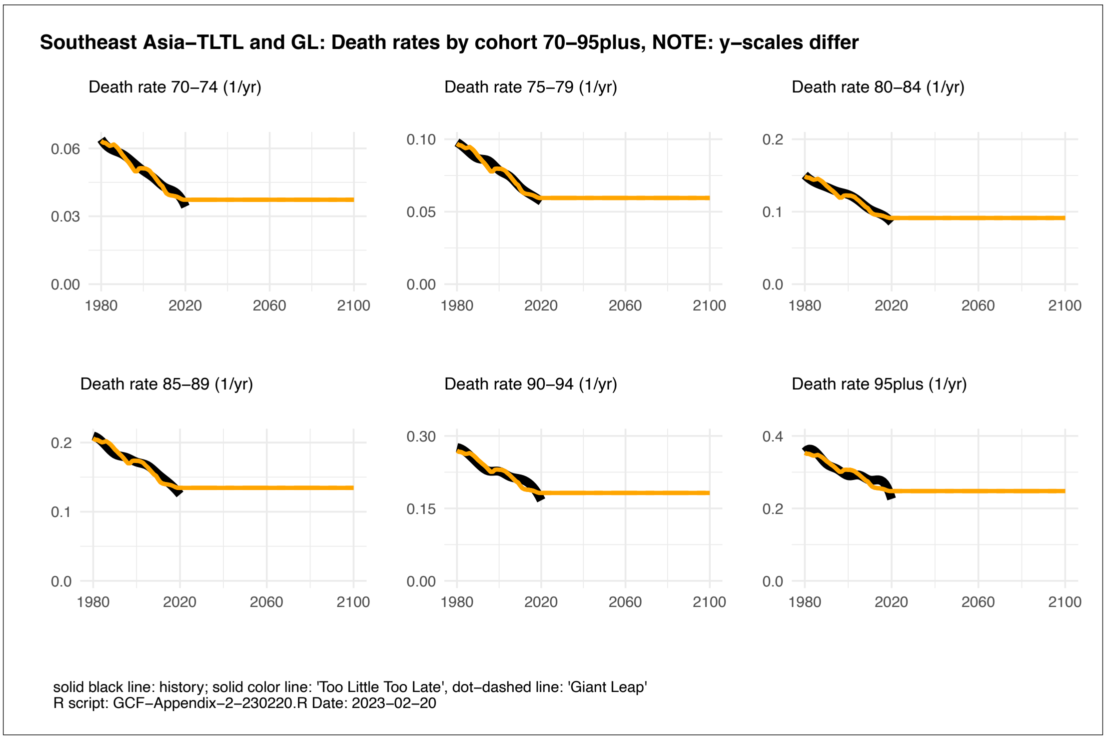
Southeast Asia–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ

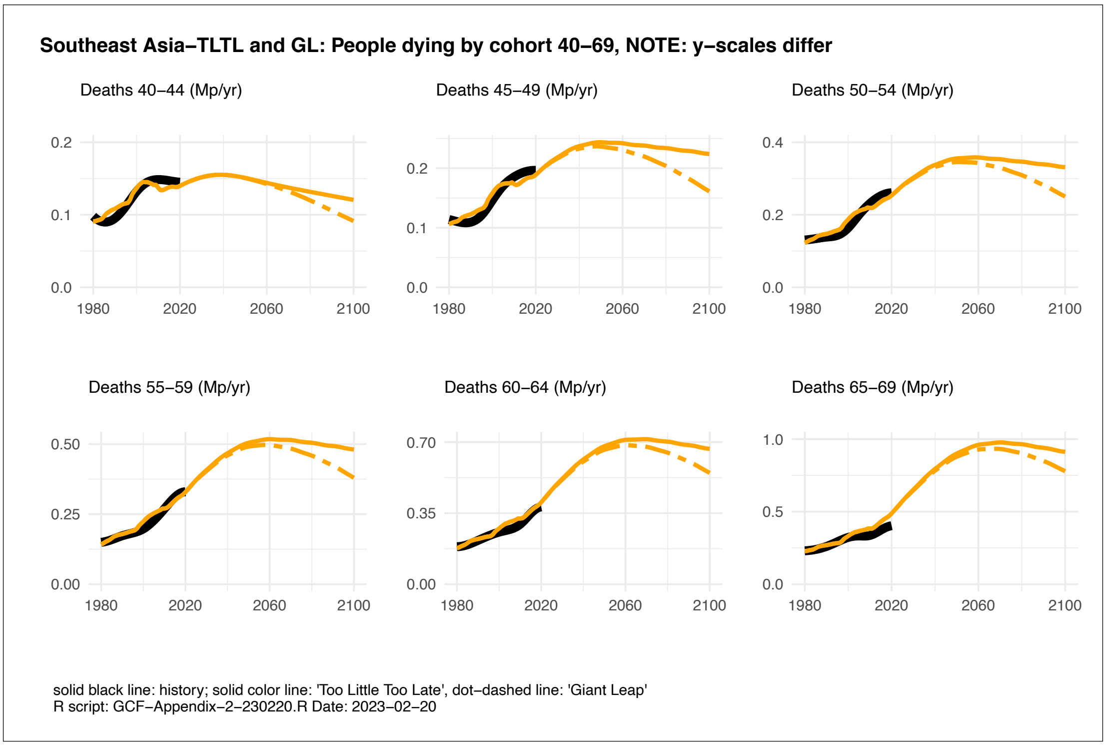


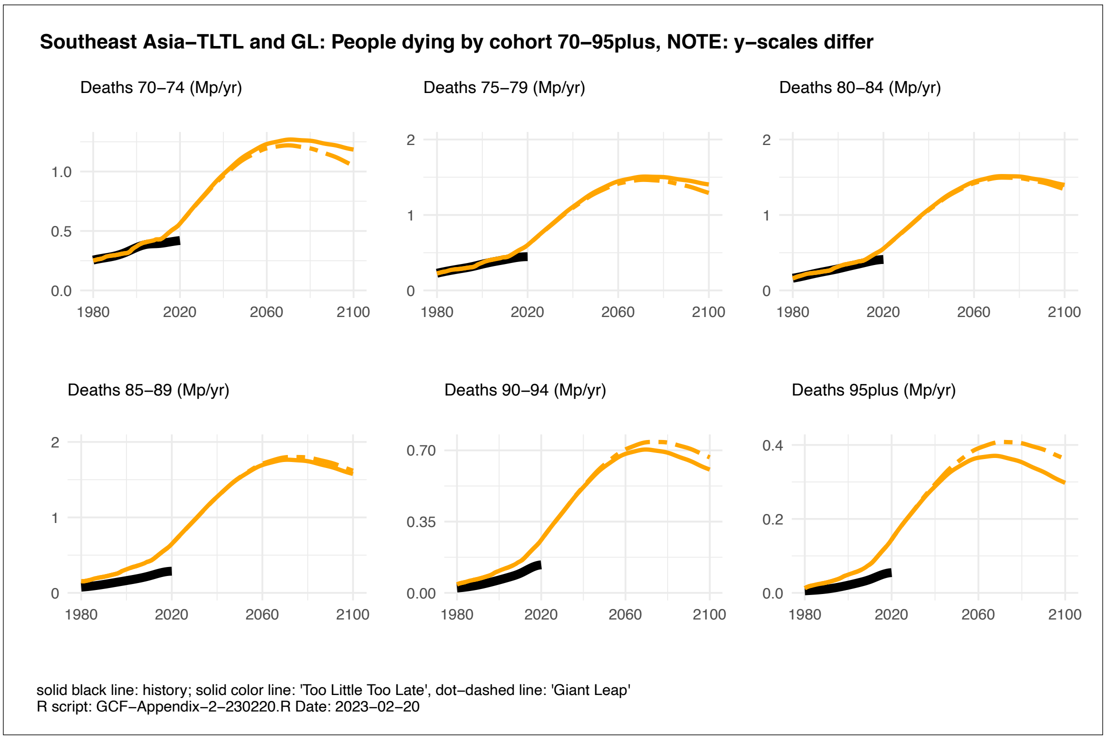
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Southeast Asia–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
60
30
0
1980
2020
2060
2100
Births (Mp/yr)
10
5
0
Deaths 0–4 (Mp/yr)
1.0
0.5
0.0
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


Southeast Asia–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
0.006
0.003
0.000
Death rate 45–49 (1/yr)
0.008
0.004
0.000
Death rate 50–54 (1/yr)
0.010
0.005
0.000
Death rate 55–59 (1/yr)
0.02
0.01
0.00
Death rate 60–64 (1/yr)
0.030
0.015
0.000
Death rate 60–64 (1/yr)
0.030
0.015
0.000
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

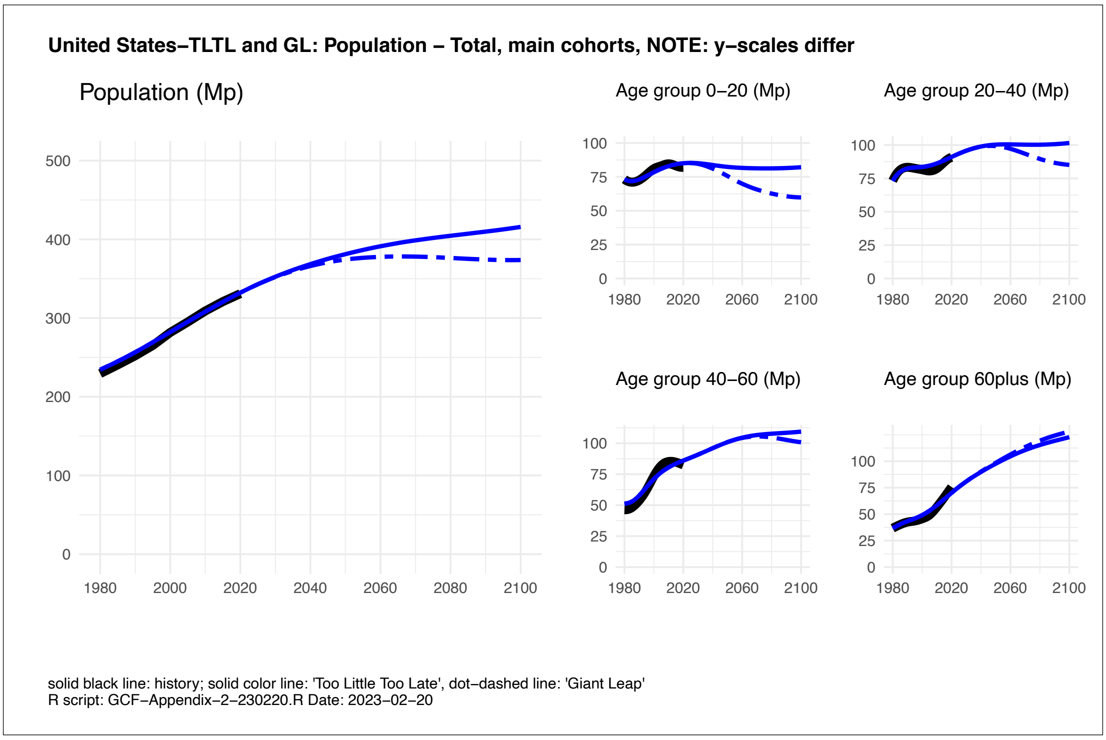

Southeast Asia–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ
Death rate 70–74 (1/yr)
Death rate 75–79 (1/yr)
Death rate 80–84 (1/yr)
Death rate 85–89 (1/yr)
Death rate 90–94 (1/yr)
Death rate 95plus (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

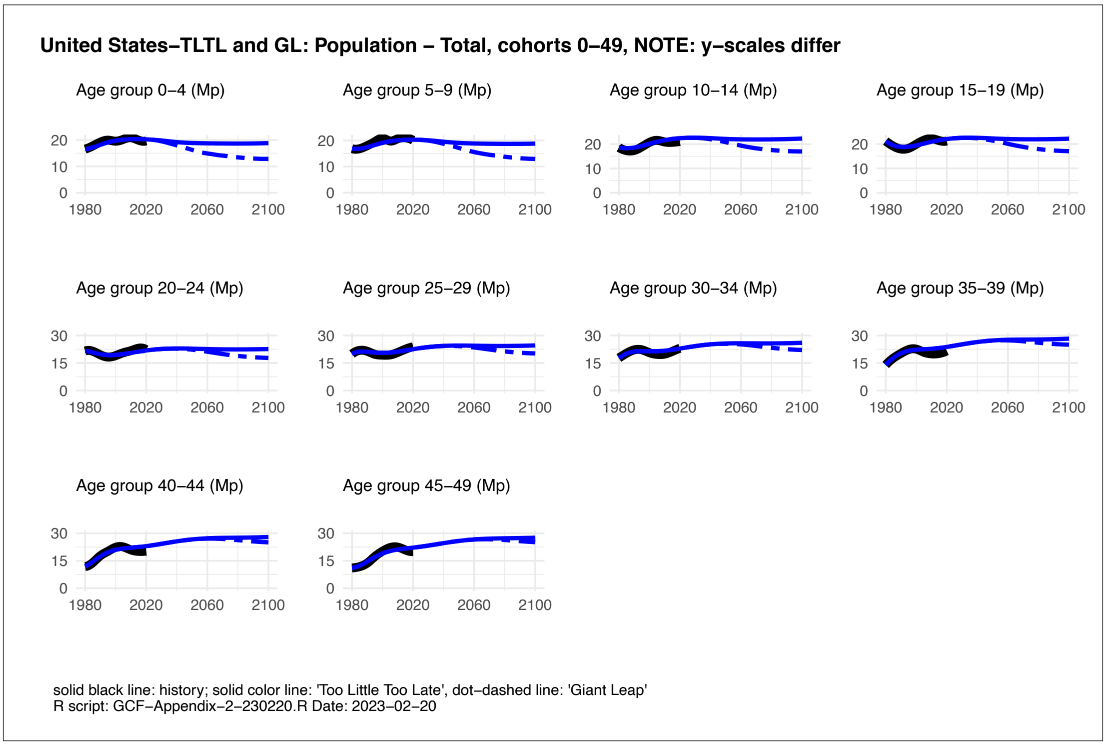

Southeast Asia–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ
Deaths 40–44 (Mp/yr)
Deaths 45–49 (Mp/yr)
Deaths 50–54 (Mp/yr)
Deaths 55–59 (Mp/yr)
Deaths 60–64 (Mp/yr)
Deaths 65–69 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

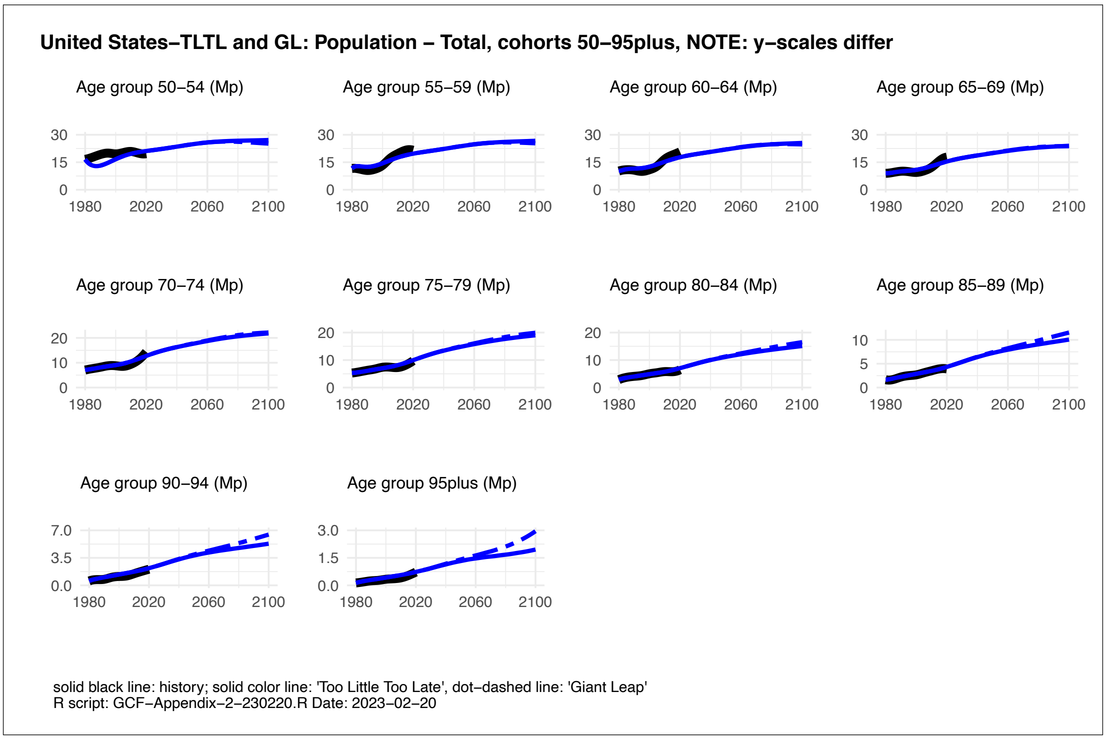


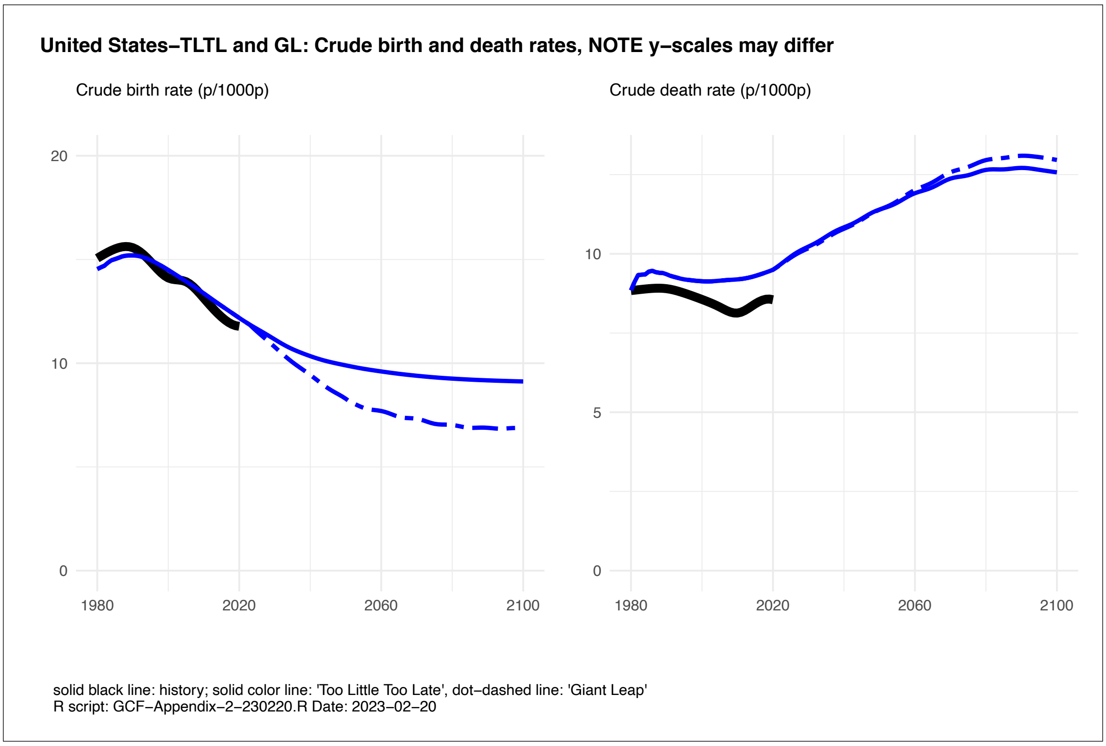
Southeast Asia–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

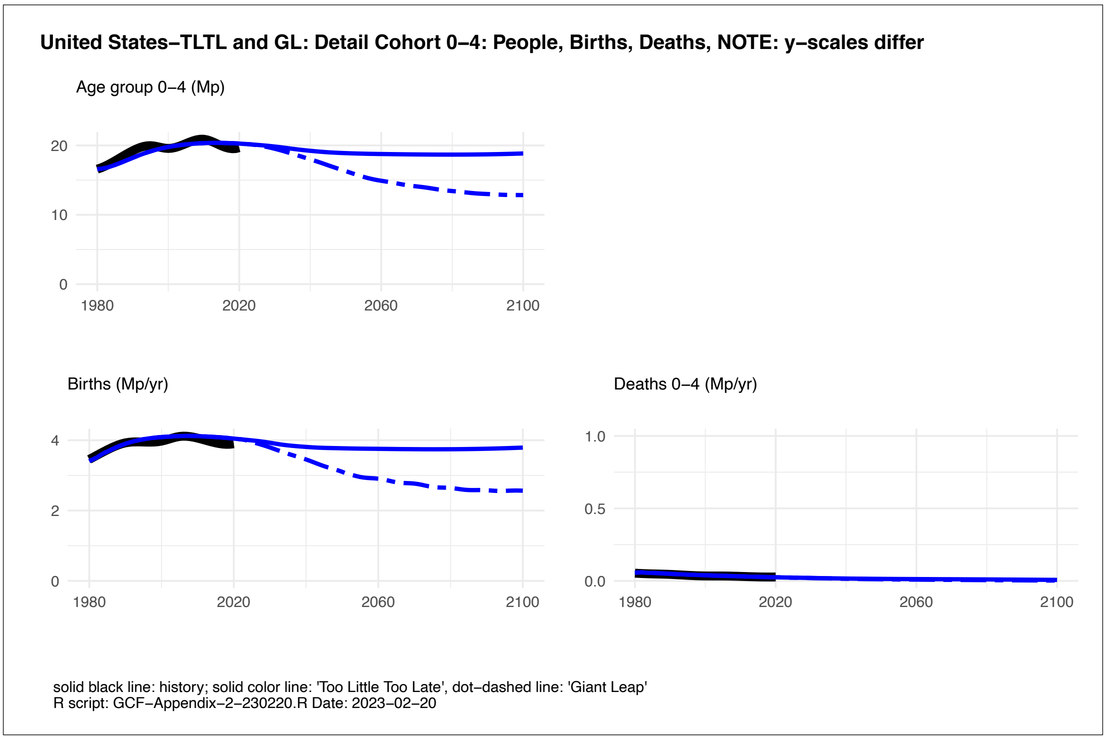
Regional Data E4A – United States demographics 1980–2100

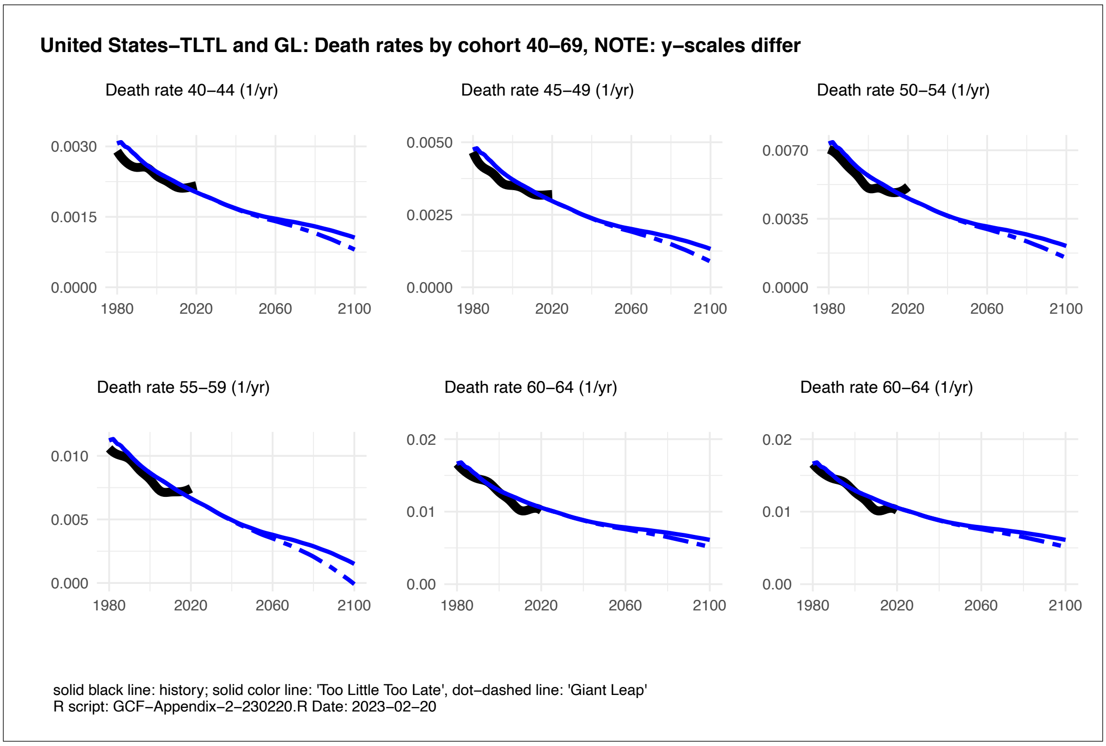




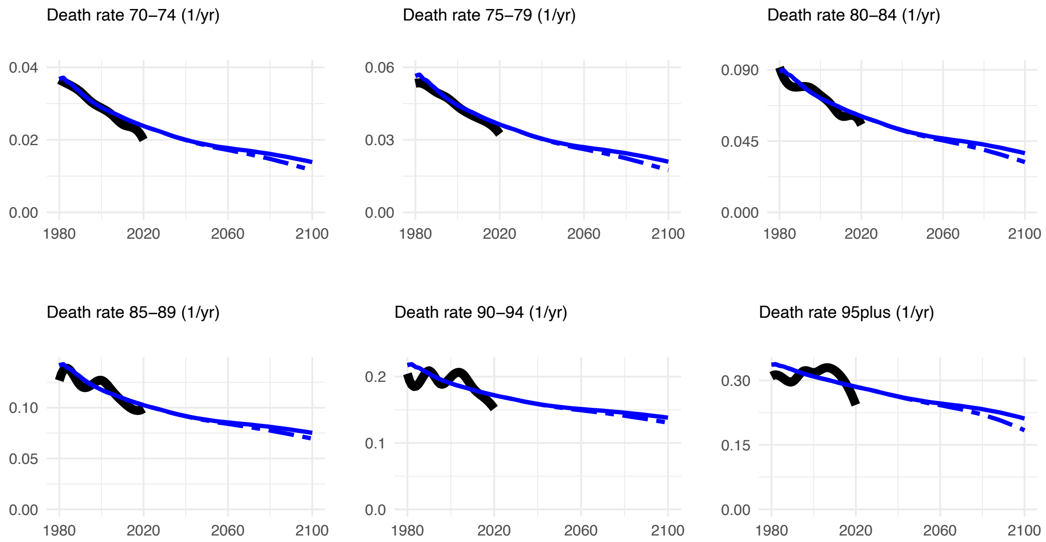

United States–TLTL and GL: Population – Total, cohorts 50–95plus, NOTE: y–scales differ
Age group 50–54 (Mp)
Age group 55–59 (Mp)
Age group 60–64 (Mp)
Age group 65–69 (Mp)
Age group 70–74 (Mp)
Age group 75–79 (Mp)
Age group 80–84 (Mp)
Age group 85–89 (Mp)
Age group 90–94 (Mp)
Age group 95plus (Mp)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


United States–TLTL and GL: Crude birth and death rates, NOTE y–scales may differ
Crude birth rate (p/1000p)
Crude death rate (p/1000p)
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


United States–TLTL and GL: Detail Cohort 0–4: People, Births, Deaths, NOTE: y–scales differ
Age group 0–4 (Mp)
Births (Mp/yr)
Deaths 0–4 (Mp/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

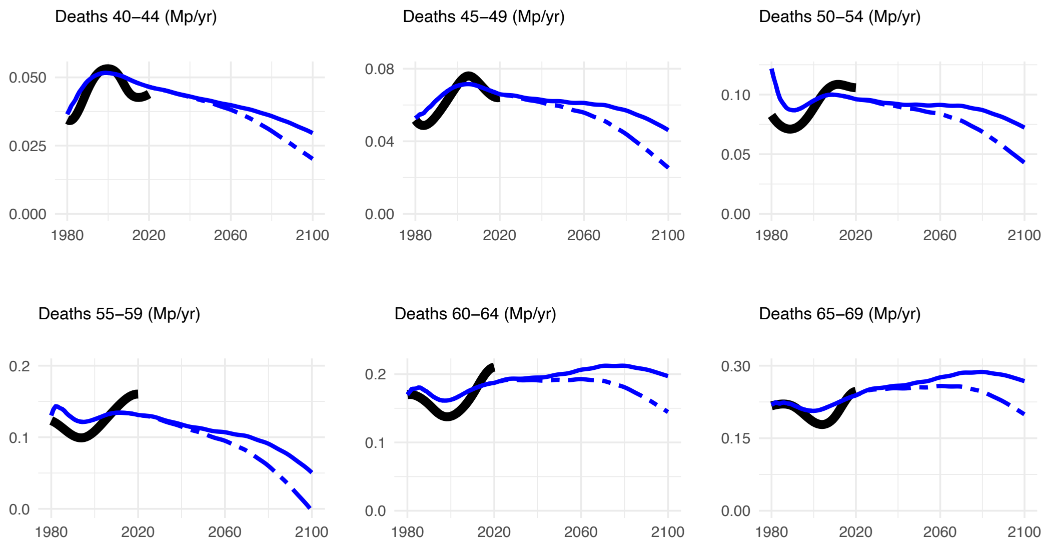

United States–TLTL and GL: Death rates by cohort 40–69, NOTE: y–scales differ
Death rate 40–44 (1/yr)
Death rate 45–49 (1/yr)
Death rate 50–54 (1/yr)
Death rate 55–59 (1/yr)
Death rate 60–64 (1/yr)
Death rate 60–64 (1/yr)
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

United States–TLTL and GL: Death rates by cohort 70–95plus, NOTE: y–scales differ

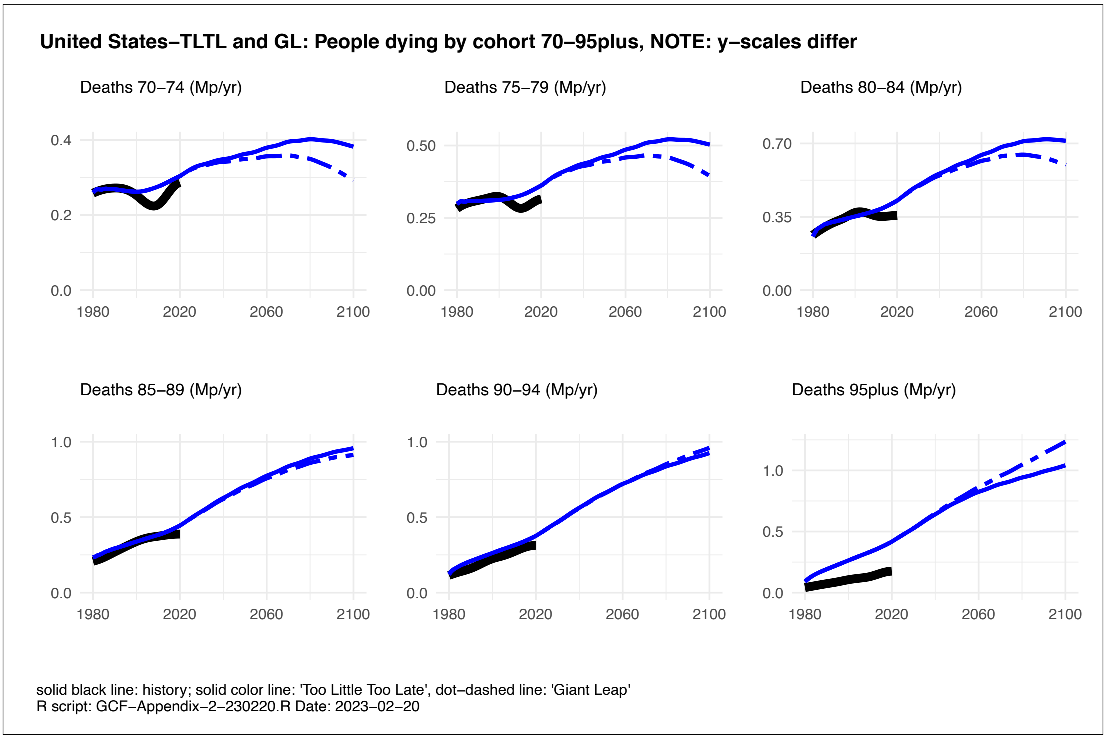


solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20

United States–TLTL and GL: People dying by cohort 40–69, NOTE: y–scales differ



solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20


United States–TLTL and GL: People dying by cohort 70–95plus, NOTE: y–scales differ
Deaths 70–74 (Mp/yr)
Deaths 75–79 (Mp/yr)
Deaths 80–84 (Mp/yr)
Deaths 85–89 (Mp/yr)
Deaths 90–94 (Mp/yr)
Deaths 95plus (Mp/yr)
0.4
0.2
0.0
0.50
0.25
0.00
0.70
0.35
0.00
1.0
0.5
0.0
1980
2020
2060
2100
solid black line: history; solid color line: 'Too Little Too Late', dot–dashed line: 'Giant Leap'
R script: GCF–Appendix–2–230220.R Date: 2023–02–20