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Source: *Demographic Research* , JANUARY - JUNE 2023, Vol. 48 (JANUARY - JUNE 2023), pp. 353-372

Published by: Max-Planck-Gesellschaft zur Foerderung der Wissenschaften

Stable URL: https://www.jstor.org/stable/10.2307/48728208

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DEMOGRAPHIC RESEARCH

VOLUME 48, ARTICLE 13, PAGES 353–372
PUBLISHED 10 MARCH 2023
http://www.demographic-research.org/Volumes/Vol48/13/
DOI: 10.4054/DemRes.2023.48.13

Descriptive Finding

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Demographic Research: Volume 48, Article 13
Descriptive Finding

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Abstract

BACKGROUND

Population aging is a fundamental element of the demographic transition. In the absence of births, deaths, and migration, the mean age of any population will increase one year per calendar year. The intensity of period birth, death, and migration conditions (i.e., their crude rates and the difference between their mean age and the mean age of the population) either lessen or strengthen this natural tendency of populations to age.

OBJECTIVE

We investigate the contribution of births, deaths, and migration to population aging across the globe from 1950 to 2100. We examine whether a concerted pattern of population aging is associated with changes in period demographic conditions.

METHODS

We apply a mathematical expression proposed by Preston, Himes, and Eggers (1989) that decomposes the rate of change in the mean age of a population according to period demographic conditions. We use the 2022 revision of the United Nations population estimates and projections covering 236 countries or areas.

RESULTS

During the demographic transition, population aging follows a general concerted pattern characterized by five distinct stages. Populations age because of declining inflows (births) at age zero and insufficient outflows (deaths) at older ages. Overall, migration does not play a pivotal role but can be more relevant in specific countries or regions.

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CONTRIBUTION

Our study combines long-time series data for most countries in the world with an elegant mathematical solution proposed by Preston, Himes, and Eggers (1989) to empirically measure the dynamics of population aging according to period demographic conditions.

1. Introduction

The world has witnessed declining mortality, fertility, and population growth rates. As a result, young age distributions have become older, and increasing numbers of middle and old-age adults have replaced the many existing youths (Lee 2003; Dyson 2010). Demographic research in population aging has a long history. Scholars have examined population aging in various contexts and from distinct angles, theoretically and empirically.

On one of the many fronts, demographers have studied population aging using the stable population model (Lotka 1922, 1939; Coale 1957; Keyfitz 1968; Coale 1972; Preston 1974; Keyfitz 1977; Lee 1994; Alho 2008). Other scholars have used counterfactual population projections (Lorimer 1951; Hermalin 1966; Yu and Horiuchi 1987; Grigsby and Olshansky 1989; Espenshade 1994; Moreira 1997; Heuveline 1999; Jonsson and Rendall 2004; Bengtsson and Scott 2010; Lee and Zhou 2017). Both approaches have limitations in explaining what happens to the age distributions of populations. On the one hand, the stable population model has limited applicability since only a few modern populations meet the condition of stability (Preston, Himes, and Eggers 1989; Preston and Stokes 2012; Lee and Zhou 2017). On the other hand, counterfactual population projections assume unrealistic scenarios (i.e., constant mortality or fertility over very long periods). They are sensitive to the choice of the starting date, which may lead to conflicting conclusions (Murphy 2017). Although distinct, both methods consistently conclude that fertility decline is the primary determinant of population aging (Siegel 1980; Dyson 2010).

In the late 1980s, Preston, Himes, and Eggers (1989) develop two mathematical expressions that improve our understanding of the demographic determinants of population aging. They decompose the rate of change in the mean age of a population into its period or cohort effects. The first expression (PHE-I) begins with the fact that in the absence of births, deaths, and migration, the mean age of any population will increase one year per calendar year. The intensity of period demographic conditions will either lessen or strengthen this natural tendency of populations to age. PHE-I decomposes the rate of change in the mean age of a population into period birth, death, and migration conditions (i.e., their crude rates – the product of age-specific demographic rates and population age structure, and age selectivities – the differences between their mean ages and the mean age of the population). The second expression (PHE-II) deals with cohort processes. It relates the rate of change in the mean age of a population with age-specific growth rates, which reflect differences in the number of births and cumulative age-specific mortality and net migration rates of successive birth cohorts (Preston and Coale 1982; Horiuchi and Preston 1988).[4] Later, Murphy (2017) extends PHE-II by decomposing the birth cohort component into a fertility rate term and the corresponding population at risk.

Scholars prefer to apply PHE-II to PHE-I because it relates population aging more clearly to demographic history. There are studies for Italy and France (Caselli and Vallin 1990) and Japan (Horiuchi 1991), which are based on Horiuchi and Preston (1988); the United States and Sweden (Preston, Himes, and Eggers 1989; Preston and Vierboom 2021); and different groups of countries (Preston and Stokes 2012; Murphy 2017). However, PHE-II demands a minimum of one hundred years of continuous data to calculate the first change of the mean ages, which has limited its applicability to short-term intervals and a few regions of the world.

PHE-I, in turn, is a simple and elegant mathematical expression that focuses on the period determinants of population aging. It relies on period crude rates and age selectivities; an example is Myrrha, Turra, and Wajnman (2017), which applies PHE-I to Brazil for 1950–2100. Because PHE-I requires only period data, it exponentially increases our ability to examine more extended periods and more countries. Also, because most public opinion on population aging is formed by looking at period demographic flows (The Economist 2017, 2021; Editorial Board 2022; Raftery 2021; Bush 2022; Jordan and Gebeloff 2022), its results are attractive to a broader audience.

The international literature lacks systematic comparative analyses of the role of period rates on population aging. We address this gap by applying PHE-I to the official United Nations population estimates and projections from 1950 to 2100. Since the demographic transition has varied concerning the onset, pace, and scale of mortality and fertility declines (Reher 2004, 2011), we detail our analyses by the world's 22 subregions. We have two primary objectives. First, we decompose the rate of change in the mean age of a population in terms of birth, death, and net migration rates. Second, we examine whether population aging has evolved alongside a general concerted pattern associated with changes in birth and death rates.

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[4] PHE-II (Preston, Himes, and Eggers 1989: 696) is expressed as:

$$\frac{dA_p}{dt} = \int_0^\infty r(a,t) \cdot c(a,t) \cdot [a - A_p(t)]\, da \qquad \text{(PHE-II)}$$

where dA_p/dt is the first derivative of the mean age of the population (A_p) to time (t). On the right-hand side, $r(a,t)$ is the age-specific population growth rate, and $c(a,t)$ is the age-specific proportion in the total population.

2. Population aging as a function of period demographic rates

PHE-I builds upon one fundamental demographic certainty: every person becomes one year older every calendar year. In the hypothetical scenario of no births, deaths or migration, any population naturally tends to age at the same rate. The intensity of period birth, death, and migration rates and their age selectivity will either lessen or strengthen the natural tendency of populations to age. Births always rejuvenate populations by entering at age zero, reducing populations' mean ages. In-migrants rejuvenate populations if their mean age is below the mean age of the population. In contrast, deaths and out-migrants rejuvenate populations if they occur, on average, at ages older than the mean age of the population. These associations are expressed as (Preston, Himes, and Eggers 1989: 695):

$$\frac{dA_p}{dt} = 1 - b \cdot (A_p) - i \cdot (A_p - A_i) - d \cdot (A_D - A_p) - o \cdot (A_o - A_p) \qquad \text{(PHE-I)}$$

where dA_p/dt is the first derivative of the mean age of the population (A_p) to time (t). On the right-hand side, 1 is the population's natural tendency to age every period. The rejuvenating effects are the products of the demographic rates – birth (b), in-migration (i), death (d), and out-migration (o) – and the age selectivity of each one of them. The migration components of PHE-I refer to the direct effect of migration (migrants as such). The indirect effects of migration (births from in-migrant mothers and deaths of in-migrants after migration) are reflected in the birth and death components.

3. Data and method

We use data from the 2022 Revision of the United Nations population estimates and projections (United Nations 2022a,b). The 2022 Revision covers 150 years, including estimates (1 January 1950 to 1 January 2022) and projections (1 January 2022 to 1 January 2101). We use the 1 January medium-fertility projection variant for 236 countries or areas with at least 1,000 inhabitants in 2021 by single year of age, one-year time interval, and for both sexes combined. Also, we adopt the United Nations standard of five continental geographic regions – Africa, Americas, Asia, Europe, and Oceania – with the respective 22 subregions (United Nations 2019).

Any population projections involve inaccuracy and uncertainty. Therefore, our analysis for the years after 2022 is hypothetical. However, earlier studies show that the United Nations population prospects are reasonably reliable and have improved (Buettner 2021). Also, projections are valuable data that have been extensively used in the study of population aging (Siegel and Davidson 1984; Chesnais 1990; Cutler et al. 1990; Keyfitz and Flieger 1991; Martin and Preston 1994; Lee 2003; Goldstein 2009; Rowland 2009; National Research Council 2012; Ashraf, Weil, and Wilde 2013; Bloom and Luca 2016; Lee 2016; He, Goodkind, and Kowal 2016).

The 2022 Revision's data is limited to net numbers of migrants ($I - O$) and net migration rates ($i - o$). Consequently, we cannot calculate migration age schedules and estimate the mean age of in-migration (A_i) or out-migration (A_o). Thus, we apply an approach used elsewhere (Preston, Himes, and Eggers 1989; Preston and Stokes 2012; Preston and Vierboom 2021) and compute the rejuvenating effect of net migration as a residual effect in PHE-I (ρ_{io}):

$$\rho_{io} = i \cdot (A_p - A_i) + o \cdot (A_o - A_p) \tag{1}$$

$$\implies \rho_{io} = \Big(1 - b \cdot (A_p) - d \cdot (A_D - A_p)\Big) - \frac{dA_p}{dt} \tag{2}$$

Residuals incorporate measurement errors (e.g., discrete approximation, data inconsistencies). However, our results show that the rejuvenating effects of net migration are close to zero when absolute net migration rates are less than 0.0001 (1 per 10,000 population), suggesting no critical inconsistencies in the UN estimates.

We calculate the weighted mean age of each population (A_p) from 1950 to 2100 by multiplying the mid-point in every one-year age group by the corresponding population size and then summing the values up. For the open-age interval (100 years and older), we use life expectancy at age 100 (e_{100}) as the midpoint age, extracted from period life tables. To estimate the weighted mean age of deaths (A_D), we multiply the mean ages at death (a_x) from the period life tables by the proportionate distribution of deaths by age.

4. The role of period demographic flows on population aging

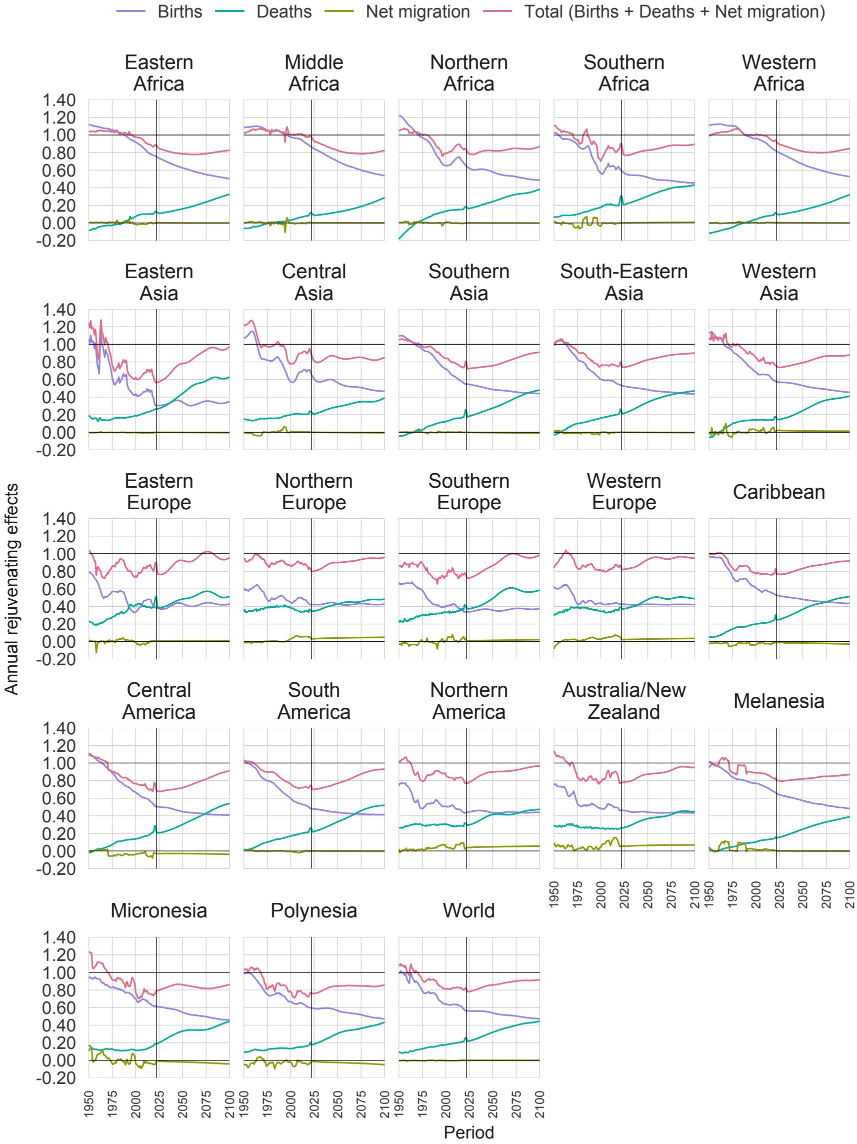
In the absence of births, deaths, and migration during the 150 years covered by the 2022 UN Revision, the mean age of any population would have increased by the same 150 years, that is, one year per calendar year. However, the world population is expected to age at a much lower rate of 0.11 per year due to the rejuvenating effects exerted by demographic flows. Figure 1 presents these effects according to the world's 22 subregions. Vertical lines in 2022 separate the UN estimates from the projections. Over most of the analysis period (1950–2100), the total rejuvenating effect lies between 0.8 and 1.0 year per calendar year, compensating for most but not all the natural tendency of populations to age.

The trajectory of rejuvenating effects is somewhat similar in the subregions. However, there are differences in the roles played by births and deaths due to the distinct stages of the demographic transition across the globe. Around the 1950s, the rejuvenating effect of births was close to or larger than 1 in Africa, Asia, and South and Central America. It was stronger than in Europe and North America, where it was between 0.6 and 0.8 year per calendar year. As crude birth rates reduce, the rejuvenating effect of births converges to 0.4 in all subregions, compensating for less than half of the natural rate of population aging. At the same time, deaths wield a weak rejuvenating effect in the subregions that started the demographic transition in the 20th century. However, over the decades, its magnitude increases significantly, together with the crude rate and age selectivity of deaths. In the subregions that pioneered the demographic transition, the rejuvenating effect from deaths changes much less.

These findings are consistent with Preston, Himes, and Eggers (1989). Based on stable populations, the authors demonstrate that under high levels of mortality and fertility, the effect of births compensates for almost all (80%–100%) of the natural tendency of the mean age of the population to increase. Under low levels, the effect of births compensates for 40%, whereas the effect of deaths compensates for about 60%.

In all subregions, the rejuvenating effects of net migration are substantially weaker than those from the other two components. Projecting migration incorporates the highest uncertainty among all demographic variables and is subject to unanticipated changes (e.g., refugees). However, even if we limit our analysis to the UN estimates (1950 to 2022), the rejuvenating effects of net migration are minor, lying in the range of –0.05 to 0.05 year per calendar year. Still, some patterns are worth noting when we accumulate these effects from 1950 to 2022. Net migration flows had close to zero impact on population aging in Africa, except for Southern Africa, where they helped populations to get older faster. Net migration also increased the mean age of Asian populations, except in Western Asia. Europe has a divided scenario. Net migration rejuvenated populations in Northern and Western Europe, while they had a near-null effect in Eastern and Southern Europe. The Americas and Oceania present a mixed picture. Net migration rejuvenated populations in Northern America, Australia/New Zealand, and Melanesia as well as the aged populations in the Caribbean, Central America, and Polynesia, and had close to zero effect in South America and Micronesia.

Figure 1: Annual rejuvenating effects of births, deaths, net migration and total, world's subregions, 1950–2100



Source: Prepared by the authors based on United Nations (2022b).

5. Distinct stages of population aging

Next, we examine whether the mean ages of populations have increased under a general concerted pattern between the rejuvenating effects of births and deaths. Since net migration has proved to be a much paler force, we ignore it in this section to keep the analysis simple. Adding net migration would not change any of our conclusions.

In Figure 2, we display each one-year rejuvenating effect of deaths (x-axis) against the rejuvenating effect of births (y-axis) for all 236 countries or areas of the 2022 Revision. We draw a line we call the mean age stability line. Over this line, the combined effect of births and deaths is equal to 1, compensating entirely for the natural tendency of the mean age of populations to increase. Thus, on this line, populations are becoming neither older nor younger. Populations above this line have combined effects of births and deaths greater than 1 and are thus becoming younger. Populations below this line have total effects lower than 1 and are becoming older. Figure 2 suggests a general concerted pattern of population aging between the rejuvenating effects of births and deaths. We identify seven stages and summarize them in Table 1.

Table 1: Stages of population aging according to the rejuvenating effects of births and deaths

Stage	Mean age		Rejuvenating effect of births	Rejuvenating effect of deaths	Combined rejuvenating effect of births and deaths	Example countries
	A_p	dA_p/dt				
1	decrease	negative	1.0, 1.4	−0.4, 0.0	> 1	Mexico (1950) Afghanistan (1980)
1A	minimum	zero	1.0	0.0	$= 1$	Turkey (1965) Somalia (2010)
2	increase	positive	0.6, 1.0	0.0, 0.2	< 1	Bulgaria (1950) China (1971)
3	increase	maximum	0.6	0.2	< 1	Japan (1971) South Africa (2005)
4	increase	positive	0.4, 0.6	0.2, 0.6	< 1	United States (1969) France (1975)
4A	maximum	zero	0.4	0.6	$= 1$	Portugal (2067) Greece (2073)
5	decrease	negative	0.4	> 0.6	> 1	Ukraine (2071) Spain (2071)

Source: Prepared by the authors based on United Nations (2022b).

At Stage 1, birth and death rates are initially very high (Figure 3a and Figure 4a). Deaths are concentrated in infancy and childhood ages. Therefore, the mean age of deaths is lower than the mean age of the population, and the age selectivity of deaths is negative

(Figure 4b). As a result, populations start by facing low negative rejuvenating effects of deaths (between –0.4 and 0.0) and high rejuvenating effects of births (1.0 to 1.4). The combined effects are greater than 1, and thus populations become younger.

As the demographic transition starts, mortality declines primarily at the first ages of life, and the age distribution of deaths shifts to older ages. The effect of deaths approximates zero from the rise of the age selectivity of deaths (Figure 4b) and the decline in death rates (Figure 4a). Birth rates also start to decline, and the effect of births reduces, getting closer to 1 (Figure 3a). At the end of the first stage (Stage 1A), the combined effect of births and deaths crosses the mean age stability line.

At Stage 2, crude death rates keep reducing (Figure 4a). But a rapid increase in the age selectivity of deaths (Figure 4b) turns them into a rejuvenating force, though still weak. As populations become older, the age selectivity of births also increases (Figure 3b). However, the decline in crude birth rates dominates, and the rejuvenating effect of births loses strength. The combined rejuvenating effect of deaths (0.0 to 0.2) and births (0.6 to 1.0) become less than 1. Population aging is underway.

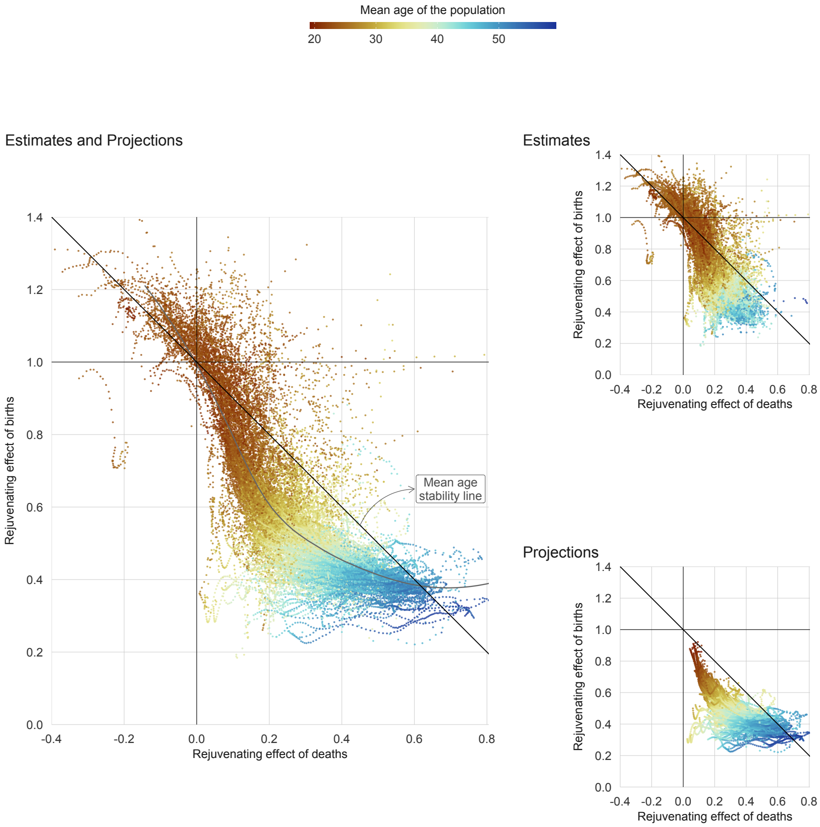
At Stage 3, the demographic transition advances, and the rejuvenating effects of deaths and births are around 0.2 and 0.6, respectively. Gradually, the effects of deaths increase, replacing births to compensate for the natural tendency of population aging. However, the combined effect reduces due to the rapidly declining birth rates (Figure 3a). With even fewer births per person-years, populations age faster than before. The annual change in the population's mean age reaches a local maximum.

In Stage 4, mortality improvements concentrate primarily on middle and old ages, and the mean age of the population increases faster than the mean age of death. Thus, the age selectivity of deaths stops rising (Figure 4b). However, death rates increase somewhat, despite the mortality decline, because of changes in the age structure. Consequently, the rejuvenating effect of deaths strengthens as deaths take individuals older than the mean age out of the population. Fertility levels also continue to decline, but now more gradually, and with a more significant fraction of the population at adult ages, birth rates tend to decrease slower (Figure 3a).

Nonetheless, the age selectivity of births increases faster with population aging. As a result, the effect of births is only a little lower than in Stage 3. Populations keep becoming older at a slower rate. At the end of Stage 4, combined births and deaths stop the mean age from changing. The mean age reaches a local maximum, and the mean age stability line is crossed again, which we indicate as Stage 4A.

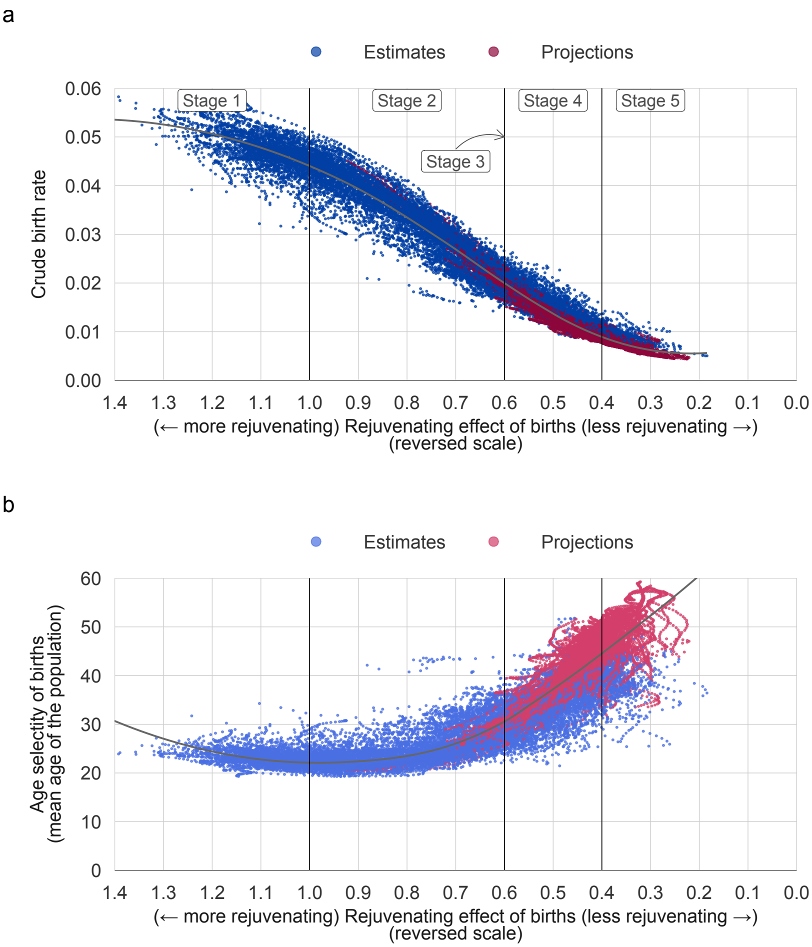
The stable aged population is not the end of the story, according to the 2022 Revision's projections. There is a hypothetical Stage 5. The combined rejuvenating effects of births and deaths are greater than 1; thus, populations become younger – not young – repeating Stage 1. But now, the effect does not come from births as at the beginning of the demographic transition. Fertility levels stabilize, and birth rates stay about the same as in Stage 4 (Figure 3a). It derives from mortality changes and the older population age structures. The age selectivity of deaths varies little (Figure 4b). However, despite lower mortality levels, crude death rates increase from the older age distributions (Figure 4a), making deaths reduce the mean age of the population slightly. Stage 5 does not change the fact that populations are much older after decades of population aging.

Figure 2: Rejuvenating effect of deaths by rejuvenating effect of births



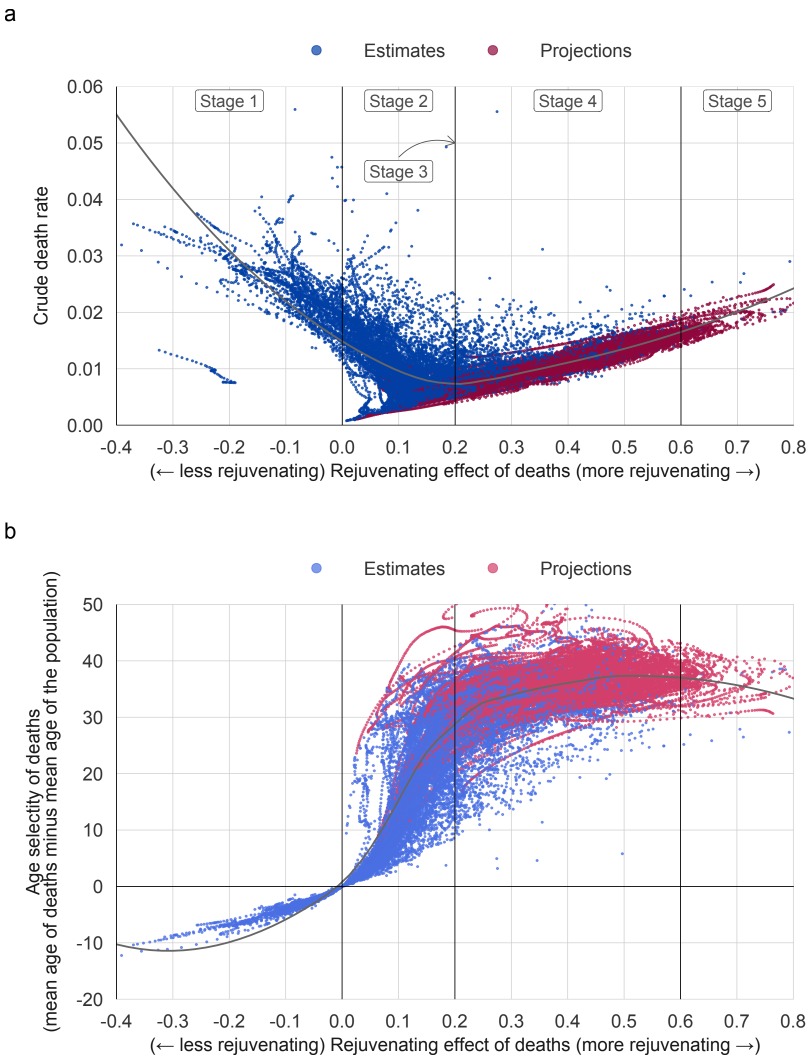
Source: Prepared by the authors based on United Nations (2022b).

Figure 3: **Rejuvenating effect of births by crude birth rate (a) and age selectivity of births (b)**



Source: Prepared by the authors based on United Nations (2022b).

Figure 4: Rejuvenating effect of deaths by crude death rate (a) and age selectivity of deaths (b)



Source: Prepared by the authors based on United Nations (2022b).

6. Discussion

This study investigated the role of period demographic conditions on population aging in diverse demographic contexts. Consistent with Preston, Himes, and Eggers (1989) stable populations' comparative statics, our findings show that population aging is initially mainly determined by births and ultimately by a balance between births and deaths. Net migration does not play a pivotal role in population aging but eventually can become more critical once one looks at specific subregions. From 1950 to 2022, net migration contributes to age populations in the Caribbean and Central America or rejuvenates them in Northern and Western Europe, Northern America, and Australia/New Zealand.

Despite local idiosyncrasies, our proposed framework suggests that population aging differs alongside a general concerted pattern between the rejuvenating effects of births and deaths. Populations initially experience one stage when they become younger, then three stages when they become older, and finally, another stage when they become slightly younger. For any population in the world, one can quickly determine these stages by looking at crude rates and the age selectivity of demographic flows.

This study's main strengths and limitations are associated with data. It uses the most updated, comprehensive (236 countries or areas), and detailed (one-year periods and age groups) data of the United Nations population estimates and projections. However, the historical estimates' quality and the projections' uncertainty may affect our conclusions. For example, Stage 5 results from unchanged fertility levels, the decline of mortality rates, mostly at old ages, and the continuous increase in the crude death rate. It may not happen if future mortality and fertility changes differ from the adopted hypotheses. Therefore, the reader should be cautious in taking our findings for the years after 2022 since they are only hypothetical.

PHE-I focuses on period demographic conditions, which are the product of interacting age-specific rates with the population age structure. Therefore, one should not see the rejuvenating effects as isolated impacts of each demographic variable since they also carry historical demographic marks carved in the age structure. Regardless of the historical reasons for birth rates to vary – if due to fertility or infant/youth mortality changes – reducing the relative number of births leads to population aging. Deaths play a distinct role in this process because they are outflows. From a period perspective, declines in mortality help populations age primarily by reducing exits at ages older than the mean age of the population. Had mortality levels not improved over time and only shifted to older ages, deaths would have been a much stronger rejuvenating effect inhibiting population aging. Therefore, after decades of mortality and fertility changes that characterize the demographic transition, populations ultimately age because there are declining inflows (births) at age zero and not enough increasing outflows (deaths) at older ages.

7. Acknowledgments

An earlier version of this paper was presented at the 2019 Annual Meeting of the Population Association of America. The authors thank Luís Eduardo Afonso, Flavia Andrade, Gilvan Guedes, Timothy Miller, Samuel H. Preston, Simone Wajnman, and the anonymous reviewers for their helpful comments and suggestions.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 - which funds the Demography Program at the Federal University of Minas Gerais (UFMG). The authors acknowledge support from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

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