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Guest Editors: Sergei Scherbov and Warren Sanderson

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Sergei Scherbov and Warren Sanderson

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Contents

INTRODUCTION

Warren Sanderson and Sergei Scherbov*

In the spring of 2017, a Google search of the phrase “60 is the new 50” yielded around 17,700 hits in English. When written as “sixty is the new fifty,” there were around 9,880 hits; albeit with certainly many overlaps. People understand what “60 is the new 50” means, and some of them are even walking around wearing t-shirts and hoodies that reflect that idea. So far, however, an updated understanding of what it means to be “old” has yet to reach most scholars of population aging or public officials charged with making policies related to aging. If there were an aphorism that sums up the dominant academic and policy view of population aging, it would be something like: “The new 60 is the old 60.”

It almost seems as though the ways in which population aging is conceptualized and measured have been frozen in time. In a UN analysis of population aging in the *Vienna International Plan on Aging, 1982*, people in all countries of the world were categorized as “old” upon reaching their 60th birthday. In a subsequent analysis of aging in *World Population Ageing 2015*, the point in the life course at which people were classified as “old” had not changed. Thus, implicitly, none of the changes in life expectancy and health that occurred between 1982 and 2015 were considered relevant to the study of population aging. The total dependency ratio – i.e., the ratio of people in the “dependent” age groups to people not in the “dependent” age groups, as defined by fixed chronological age boundaries – first appeared in 1913. While the new 60 may have been the old 60 in 1913, it certainly is not now.

There are some advantages to the approach to population aging based on the assumption that “the new 60 is the old 60.” For example, it solves what could be called “the Segall problem.” Segall is supposed to have said the following: “A man with a watch knows what time it is. A man with two watches is never sure.” Thus, “the new 60 is the old 60” assumption is the equivalent of having only one watch. In the study of population aging, 60-year-olds are uniformly treated

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as identical, regardless of whether they lived in Swaziland in 1950 or in Sweden in 2020. But considering the possibility that 60 may indeed be the new 50 leads us to think about the question of whether aging has to do with more than just chronological age. We are invited to wonder whether the watch that counts down to the end of our lives runs faster in some circumstances than in others.

It is important to have measures of age that depend on people's characteristics, such as their remaining life expectancy and their physical and cognitive health, because many behaviors are influenced by these characteristics. Moreover, changes in the behavioral patterns of age groups can have important economic and social implications. For example, older people are far more likely to engage in certain activities today than they were in the past, such as taking university classes, buying a house, or climbing a mountain.

In the last decade or so, new approaches to thinking about and measuring population aging have been developed. These approaches share the view that aging should be defined more by how people are living than by how long they have been alive. At each age, there are many aspects of people's lives that are relevant to the study of population aging, including how long they expect to live, how healthy they are, what activity limitations they have, how well they function physically and cognitively, and whether they receive a state-funded pension. These dimensions of people's lives differ across generations, across countries, and across subgroups of the population. The new 60 is not the old 60 when aging is viewed from a more holistic perspective. In recognition of this insight, the Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID, and WU) brought experts on aging together in November 2014 to discuss new ways of thinking about and measuring population aging. This volume is the result of that conference.

In our introductory essay, "A Unifying Framework for the Study of Population Aging," we provide a conceptual guide to the remaining papers in the volume, and show that the Segall problem need not arise in the multidimensional study of population aging. Three papers in this volume measure population aging using prospective age in addition to chronological age. Prospective age is based on remaining life expectancy. Emelyanova and Rautio examine aging in the Arctic region; while Gnajotovic and Devedzic analyze aging in Serbia; and Basten-Gietel, Sanderson, and Scherbov explore aging in emerging market economies. Two papers address the role of health in aging. Boissonnaeult and de Beer show that in 14 European countries, changes in measures of health and labor force participation among the elderly are only weakly related. Demuru and Egidi study aging in Italy by adjusting prospective ages for measures of health. Barslund et al. show how prospective ages can be used to make dependency ratios based on National Transfer Accounts data more dynamic. Novak and Palloni show that subjective survival expectations based on survey data are largely consistent with observed life expectancies. Riffe et al. add thanatological age to the mix. Thanatological age is defined as the exact number of years a person has left to live. Riffe et al. study the joint effects of prospective and thanatological age on markers of aging and disability. Rehkopf et al. investigate the relationship between biomarkers and age in two populations of people aged 60+.

The papers in this volume exemplify the ongoing transformation of the study of population aging from having been a research area that was largely static, to becoming a field of inquiry that is exciting and dynamic.

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REFEREED ARTICLES

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A unifying framework for the study of population aging

Warren Sanderson and Sergei Scherbov*

Abstract

Aging is a complex, multifaceted phenomenon. In this paper, we provide an integrative approach that allows for the study of numerous dimensions of aging within a unified framework. The framework is based on the translation of quantitative measures of people's characteristics into a new form of age measure, called "alpha-age." Two individuals who have the same alpha-age have the same level of the characteristic under consideration. Alpha-ages are easy to understand and analyze because they are measured in years, just like chronological age. Indeed, chronological age is just an alpha-age for which the characteristic is the number of years the person has lived. An advantage of using the alpha-age measure is that it allows for the translation of different characteristics into years of age. Expressing multiple characteristics that are otherwise difficult to compare using a common metric makes it possible to conduct comparative analyses that previously were not feasible. We demonstrate the integrative power of alpha-ages through a set of examples in which we present alpha-ages based on remaining life expectancy, five-year survival rates (a rough objective indicator of health), self-reported health, and hand grip strength. We also show how alpha-ages can be used to compute old-age thresholds that vary over time and place, and how alpha-ages can be used to compute intergenerationally equitable normal pension ages. By allowing for the consistent quantitative measurement of multiple aspects of aging, the integrative approach presented here provides us with new insights into the process of population aging.

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1 Introduction

A new approach to the study of population aging is needed. The current literature has two main branches. The first branch is based on the conventional aging measures produced by the United Nations that distinguish people solely on the basis of their chronological age (United Nations 2013a). A frequently used measure of population aging is the proportion of the population who are classified as "old." Various UN measures categorize people as old when they reach their 60th or their 65th birthday. But shouldn't a 65-year-old with a remaining life expectancy of five years be distinguished from a 65-year-old with a remaining life expectancy of 25 years in the study of population aging?

The second branch is a set of disconnected studies of the differing characteristics of people. For example, cognitive functioning is studied using one set of measures (Weber et al. 2014; Skirbekk, Loichinger and Weber 2012; Schneeweis, Skirbekk and Winter-Ebmer 2014; Stoet and Geary 2013; Flynn 1987), and physical functioning is studied using another set of measures (Leong et al. 2015; Sanderson and Scherbov 2014; Al Snih et al. 2004; Habibi et al. 2013; Innes 1999). It might be possible to determine that both cognitive and physical functioning improved over time in a particular country, but even in that case there would be no natural way to compare these changes.

Neither of these two branches of the literature is fully satisfactory because aging is a complex, multifaceted phenomenon in which the changes in the characteristics of people are interrelated. The conventional approach relies on aggregate measures that ignore the differences in the characteristics of people over both time and place, and thus yields results that are incomplete and biased. While studies of particular characteristics are of interest in their own contexts, they cannot be readily analyzed together.

In 2013, we provided the formal structure for a new approach to the study of population aging that united the two branches (Sanderson and Scherbov 2013). We called our methodology "the characteristics approach" to the study of population aging; and although we first gave the methodology this name in 2013, we had used it informally in our previous studies as well (Sanderson and Scherbov 2005, 2007; Lutz, Sanderson and Scherbov 2008; Sanderson and Scherbov 2008a, 2008b, 2010). The characteristics approach is based on the translation of quantitative measures of people's characteristics into a new form of age measure that we call "alpha-age." In this paper, we provide a series of examples based on our previous research that show in detail the ability of the characteristics approach to provide a unifying framework within which new aggregate measures of population aging can be produced, and specific aspects of this topic can be studied. By allowing for the consistent quantitative measurement of multiple aspects of aging, the characteristics approach can generate new insights that are relevant for both scientific study and policy formulation.

The paper is organized as follows. In Section 2, we show how alpha-ages are constructed, without referring to any particular characteristic. In the following four sections, we provide detailed examples of the usefulness of alpha-ages. In Section 3, we discuss alpha-ages using remaining life expectancy as the characteristic of interest. We also present a new tool for visualizing patterns of alpha-age changes. In Section 4, we discuss the use of alpha-ages for the study of disabilities and health. In Section 5, we discuss how alpha-ages can be used in conjunction with biomarkers and other survey-based measures. In Section 6, we describe how alpha-ages can be used to determine intergenerationally equitable normal pension ages. In Section 7, we discuss the relationships between alpha-ages and other age measures, such as thanatological ages and anticipatory ages. In Section 8, we outline some technical considerations. In Section 9, we offer some concluding thoughts.

2 The unifying framework

Our framework (Sanderson and Scherbov 2013) takes into account that the age-specific characteristics of people that are relevant for the study of population aging change over time, differ from place to place, and vary across population subgroups. Among the many age-specific characteristics that could be considered are remaining life expectancy, the probability of dying in the next few years, the proportion of the adult lifetime spent after a specific age, healthy life expectancy, the proportion of people with severe activity limitations, measures of cognitive functioning, measures based on biomarkers, and subjective life expectancy. The chief advantage of our framework is that it allows for the analysis of all of these characteristics within a single unified structure.

While chronological age is one characteristic of an individual, on its own it is insufficient to represent the multifaceted phenomenon of aging. For example, a group of 65-year-olds with a college education may be much healthier, have fewer disabilities, and have a longer remaining life expectancy than a group of 65-year-olds with less than an upper secondary education. The chronological ages of these two groups are the same, but their characteristics are likely to be quite different. To gain a deeper understanding of aging, it is crucial that we move beyond the use of measures that are based solely on chronological age by developing tools that take into account the characteristics of individuals. The approach we have developed involves translating characteristics into alpha-ages.

The basic building blocks of the unifying framework are a set of schedules of the age-specific characteristics of people indexed by r, $C_r(a)$. The schedule r can refer to different years, different places, different genders, or different subgroups of the population; or to any other feature that distinguishes groups of people.

$$k_r(a) = C_r(a),$$

where $k_r(a)$ is the level of the characteristic of individuals at chronological age a in characteristic schedule r.

If $C_r(a)$ is continuous and monotonic in age over the relevant range, holding r fixed, it can be inverted to obtain an age associated with a characteristic level.

We denote this inverse, which maps characteristics onto chronological ages, by $C_r^{-1}(k)$. Clearly,

$$a = C_r^{-1}(k_r(a)).$$

The computation of alpha-ages generally requires two characteristic schedules, which are denoted by r and s. We often treat the characteristic schedule s as a fixed standard, and hold it constant as r varies. The alpha-age corresponding to chronological age a is the chronological age in schedule s at which the level of the characteristic is the same as it is at chronological age a in schedule r. Formally,

$$\alpha = C_s^{-1}(C_r(a)).$$

Using Table 1, we provide a step-by-step example of how an alpha-age is calculated.

The steps proceed moving from left to right in Table 1. First, a chronological age of interest is chosen. In the left-most column, this age is 65. Moving to the next cell to the right, we can see that the characteristic level of 65-year-olds in schedule r is 100. The third step is to move to schedule s and find where the characteristic level is 100. The alpha-age is then shown in the fourth step as the age in schedule s at which the level of the characteristic is 100. In this example, then, the alpha-age of the 65-year-old person in schedule r would be 55, using schedule s as a standard.

If schedule r were applied to a particular group in 2000 and schedule s were applied to the same group in 1950, and the characteristic was a measure of physical strength, Table 1 would tell us that 65-year-olds in 2000 were as strong as 55-year-olds had been in 1950. In informal language, for physical strength, 65 would be the new 55.

Special cases of alpha-ages arise depending on which characteristic is used and which combination of a, r, and s is held fixed, while other combinations are allowed to vary. In the following sections, we demonstrate the unifying power of this approach through examples.

3 Prospective ages and measures

We call alpha-ages that use remaining life expectancy as a characteristic "prospective ages;" and we call measures of population aging based on prospective ages "prospective measures" of aging. Here, the characteristic schedules are simply based on the e_x columns of the life tables.

3.1 Example 1: Prospective old-age thresholds for whole populations

In Greek mythology, the Sphinx who was guarding the city of Thebes was said to have asked passers-by the following question: "What creature is four-footed in the morning, two-footed in the afternoon, and three-footed in the evening?" Travelers

Table 1:
Hypothetical example of an alpha-age computation

From characteristic schedule *r*		From characteristic schedule *s*	
a	Characteristic level, *k*	Characteristic level, *k*	α
...	...	...	...
65	100	100	55
...	...	...	...

who failed to give the correct answer were immediately killed. Oedipus is said to have given the correct answer: namely, man, because babies crawl on all fours, adults walk on two feet, and elderly people use canes. The Sphinx's division of the human lifecycle into three phases appears to be so obvious that it may seem that there is little need to discuss it. Indeed, the conventional dependency ratio divides people into the same three categories as those used by the Sphinx. Yet if we probe this issue more deeply, the boundaries between the phases become murky. People do become old, but at what point in life does this happen? The UN measures of population aging set the old-age threshold at 60 or 65, but such arbitrary cut-off points are certainly problematic.

Forty years ago, Ryder questioned the practice of setting the old-age threshold based on chronological age. He wrote:

> We measure age in terms of the number of years elapsed since birth. This seems to be a useful and meaningful index of the stages of development from birth to maturity. Beyond maturity, however, such an index becomes progressively less useful as a clue to other important characteristics. To the extent that our concern with age is what it signifies about the degree of deterioration and dependence, it would seem sensible to consider the measurement of age not in terms of years elapsed since birth but rather in terms of the number of years remaining until death. (Ryder 1975)

In previous papers (Sanderson and Scherbov 2007, 2008b, 2010; Lutz, Sanderson and Scherbov 2008), we have followed Ryder's suggestion and have chosen to use an old-age threshold based on remaining years of life. In computing the proportions of populations who are old, the UN uses age 60 as its old-age threshold. In computing the old-age dependency ratio, it classifies people as old-age dependents after they have reached their 65$^{\text{th}}$ birthday. Instead of using fixed chronological ages, we use alpha-ages based on a fixed remaining life expectancy. In this approach, people are categorized as being old based on the number of years they are expected to live, not on the number of years they have already lived. An old-age threshold based on remaining life expectancy is much more informative than an old-age

Example 1:
Prospective old-age thresholds – Table 2
$\boldsymbol{\alpha = C_s^{-1}(C_r(a),\ \alpha = C_s^{-1}(15))}$

Characteristic (C( ))	**Remaining life expectancy**
Constant Parameters	***a* and *r*** $C_r(a)$ = 15 years
Variable Parameters	***s*** *s* is a set of life tables for Brazil, China, Germany, India, Japan, Mexico, Nigeria, the Russian Federation, and the United States for the years 1960, 1980, 2000, 2010, 2025, and 2050 (both sexes combined)

threshold that does not vary. Life expectancy changes over time, differs across countries, and varies across subgroups within countries. Old-age thresholds that take this variation into account are more informative. While it is useful to recognize the phases of the lifecycle by applying an age threshold that separates those who are old from those who are not, it is not realistic to assume that this threshold never changes over time, is the same for all countries of the world, and is the same for all population subgroups.

In Example 1, we show how alpha-ages can be used to compute prospective old-age thresholds. In this case, a and r are chosen so that $C_r(a)$ = 15 years. Fifteen years was roughly the remaining life expectancy at age 65 in many low-mortality countries around 1970. In the example, s is a set of life tables for Brazil, China, Germany, India, Japan, Mexico, Nigeria, the Russian Federation, and the United States for the years 1960, 1980, 2000, 2010, 2025, and 2050. These countries were chosen on the basis of population size and geographical representativeness.

The old-age thresholds in Table 2 all correspond to the same level of the characteristic, in this case, 15 years of remaining life expectancy. Therefore, the alpha-ages in Table 2 are all constant characteristic ages. In 1960, the old-age threshold in the USA was relatively high, at 64.2; while the old-age threshold in the Russian Federation was close behind, at 63.6; and the old-age threshold in Japan was 62.0. By 2000, the situation had changed. Japan had leapt ahead to achieve a threshold age of 71.1. The mortality crisis in the Russian Federation is evident in the table: the country's old-age threshold fell to 62.4. In other words, in 2000, a 62-year-old in the Russian Federation had the same expected remaining years of life as a 71.1-year-old in Japan. The table shows that the old-age threshold increased rapidly in China as well, from 53.9 in 1960 to 64.5 in 2000.

If we were to accept the conventional view that the old-age threshold should be fixed at age 60 or at age 65, we would have to ignore the substantial changes in life expectancies over time and the differences from place to place. There is no reason to

Table 2:
Old-age thresholds

	1960	1980	2000	2010	2025	2050
Brazil	62.3	63.8	67.6	69.1	71.1	73.6
China	53.9	63.1	64.5	65.7	66.5	68.4
Germany	62.9	64.4	68.3	70.0	71.5	73.8
India	55.9	59.8	61.4	62.7	63.7	65.5
Japan	62.0	66.5	71.1	72.8	74.5	76.9
Mexico	63.5	66.2	68.4	69.6	71.4	73.8
Nigeria	54.7	57.3	57.1	57.7	59.2	61.3
Russian Fed.	63.6	64.0	62.4	63.8	64.6	66.1
USA	64.2	66.9	68.7	70.3	71.4	73.3

Source: Scherbov and Sanderson (2014), Table Re-Ageing 1.
Note: The underlying data are from United Nations (2013b).
Old-age thresholds are alpha-ages where the characteristic, remaining life expectancy, is equal to 15 years.

accept fixed old-age thresholds since alpha-age thresholds have now been computed for all UN countries (Scherbov and Sanderson 2014).

The proportions of populations who are old are shown in Table 3 for the same nine countries and the same six years using the prospective old-age thresholds in Table 2, and the fixed age of 65 upon which many conventional measures are based. The proportion old is one of the most frequently used measures of population aging, and in Table 3, it is clear that those proportions differ considerably depending on whether the old-age threshold is adjusted for life expectancy differences using alpha-ages. For example, the conventional proportion old in China is projected to increase from 0.040 in 1960 to 0.239 in 2050. The prospective proportion old is also forecasted to increase, but much more slowly, from 0.109 in 1960 to 0.192 in 2050. Substantial differences in the growth in the proportion old can be seen in all of the countries listed in Table 3, except for the Russian Federation, where the changes in life expectancy have been relatively minor. The projected proportions old for all UN countries can be found in Scherbov and Sanderson (2014). Measures of population aging using prospective old-age thresholds can also be found in Emelyanova and Rautio (2017), Stojilkovic Gnjatovic (2017), and Basten-Gietel et al. (2017).

3.2 Example 2: Prospective median ages

A commonly used measure of population aging is the change in the median age. The prospective median age is the age in the standard life table, s, where individuals have the same remaining life expectancy as the individuals at the median age in the population associated with index r.

Table 3:
Prospective and conventional proportions old

A. Prospective proportions old	**1960**	**1980**	**2000**	**2010**	**2025**	**2050**
Brazil	0.044	0.047	0.044	0.049	0.066	0.123
China	0.109	0.060	0.072	0.079	0.119	0.192
Germany	0.137	0.160	0.129	0.150	0.163	0.215
India	0.075	0.060	0.061	0.062	0.081	0.122
Japan	0.075	0.080	0.105	0.133	0.182	0.203
Mexico	0.039	0.035	0.037	0.040	0.055	0.114
Nigeria	0.077	0.060	0.060	0.055	0.049	0.054
Russian Fed.	0.069	0.109	0.156	0.141	0.172	0.188
USA	0.098	0.097	0.098	0.089	0.113	0.134
B. Conventional proportions old	**1960**	**1980**	**2000**	**2010**	**2025**	**2050**
Brazil	0.033	0.042	0.055	0.069	0.114	0.225
China	0.040	0.051	0.069	0.084	0.135	0.239
Germany	0.114	0.156	0.163	0.208	0.251	0.327
India	0.031	0.036	0.044	0.051	0.072	0.127
Japan	0.057	0.090	0.172	0.230	0.296	0.366
Mexico	0.034	0.038	0.049	0.060	0.096	0.202
Nigeria	0.028	0.028	0.028	0.027	0.028	0.038
Russian Fed.	0.061	0.102	0.124	0.131	0.167	0.205
USA	0.091	0.113	0.124	0.131	0.186	0.214

Source: Scherbov and Sanderson (2014), Table Re-Ageing 1.
Note: The underlying data are from United Nations (2013b). Prospective proportions old are proportions of the population who are at or above the prospective old-age threshold in Table 2. Conventional old-age thresholds are at age 65 and conventional proportions old are from United Nations (2013b).

Conventional and prospective median ages for selected countries are shown in Table 4. The most striking feature of that table is that it shows that conventional and prospective median ages can move in opposite directions (Sanderson and Scherbov 2005). For example, the conventional median age of the Mexican population in 1960 was 17.0 years ($a_{median\_r} = 17.0$, and $r = 1960$). The corresponding prospective median age using the Mexican life table of 2010 as a standard ($s = 2010$) was 28.1. This means that the remaining life expectancy of a 17.0-year-old Mexican in 1960 was the same as that of a 28.1-year-old Mexican in 2010. By 2010, the conventional median age of Mexicans rose to 25.9. Since r and s are the same in 2010, the prospective median age and the conventional median age are the same in that year. Therefore, while the conventional median age rose from 17.0 to 25.9 over the period 1960 to 2010, the prospective median age fell from 28.1 to 25.9.

Example 2:
Prospective median age – Table 4
$\alpha_{median} = C_s^{-1}(C_r(a_{median\_r}))$

Characteristic (C( ))	Remaining life expectancy
Constant Parameters	s s is the life table for the specified country for 2010.
Variable Parameters	***a* and *r*** a_{median_r} is the median age in the population associated with index r. r is a set of life tables (for both sexes) for Brazil, China, Germany, India, Japan, Mexico, the Russian Federation, and the USA for the years 1960, 1980, 2000, 2010, 2025, and 2050.

Table 4:
Median age (MA) and prospective median age (PMA)

	Brazil		China		Germany		India	
	MA	PMA	MA	PMA	MA	PMA	MA	PMA
1960	18.5	28.1	21.3	38.2	34.8	42.1	20.3	34.0
1980	20.3	26.1	22.0	26.3	36.8	42.6	20.2	24.5
2000	25.3	27.3	29.6	31.4	39.9	41.9	23.0	24.7
2010	29.0	29.0	34.6	34.6	44.3	44.3	25.5	25.5
2025	35.3	32.5	39.6	38.4	48.4	46.4	29.9	28.2
2050	44.5	37.9	46.2	42.8	51.5	46.6	36.7	32.8
	Japan		**Mexico**		**Russian Fed.**		**United Sates**	
	MA	**PMA**	**MA**	**PMA**	**MA**	**PMA**	**MA**	**PMA**
1960	25.5	37.5	17.0	28.1	27.1	23.9	29.6	36.4
1980	32.6	38.8	17.3	24.2	31.1	29.3	30.1	34.1
2000	41.4	43.2	23.0	24.6	36.6	38.0	35.3	36.9
2010	44.9	44.9	25.9	25.9	37.9	37.9	37.1	37.1
2025	50.2	48.2	31.5	29.0	40.8	39.3	38.8	37.0
2050	53.4	48.5	41.9	36.2	41.6	37.6	40.6	36.2

Source: Scherbov and Sanderson (2014), Table Re-Ageing 2.
Note: The underlying data are from United Nations (2013b).
PMA, or prospective median ages, are the ages in their country in 2000 at which people have the same remaining life expectancy as they have at the median age in the indicated year.

Even though the Mexicans of median age were older in 2010, those older people had longer remaining life expectancies than their 17.0-year-old counterparts in 1960. The duration from birth to median age rose over that half century, as did the expected duration from the median age to death.

3.3 Example 3: Prospective ages of 50-year-olds by educational subgroups

Prospective ages can be used to investigate differences in aging trends across population subgroups. We examine these trends using prospective ages here and in the following two examples, where we study patterns of aging across educational subgroups for EU countries (Sanderson and Scherbov 2016). In Example 3, we present the prospective age of 50-year-olds by sex and educational attainment.

Eurostat has created a dataset on remaining life expectancies for 16 European countries for various years from 2007 to 2010 by sex using consistently defined educational attainment categories (Eurostat 2013). The low education category in the dataset includes people with pre-primary, primary, and lower secondary education (ISCED levels 0, 1, and 2). The medium education category includes individuals with upper secondary and post-secondary non-tertiary education (ISCED levels 3 and 4). The high education category includes individuals with tertiary education (ISCED levels 5 and 6). As patterns of aging may differ across geographic regions, the countries are divided into Western European countries (Denmark, Finland, Italy, Malta, Norway, Portugal, and Sweden) and Eastern European countries (Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Macedonia, Poland, Romania, and Slovenia).

Example 3:
Prospective ages of 50-year-olds by education – Table 5
$\boldsymbol{\alpha = C_s^{-1}(C_r(a))}$

Characteristic ($\boldsymbol{C}$( ))	**Remaining life expectancy**
Constant Parameters	***a* and *s*** *a* = 50 years old, *s* are sex-specific life tables for Italians with at least some tertiary education
Variable Parameters	***r*** *r* is a set of life tables for 16 European countries by sex and level of education (latest available year)

In this analysis, chronological age, *a*, is held constant at age 50, and *s* refers to the sex-specific life table for Italians with at least some tertiary education. In

Table 5:
Prospective ages of 50-year-olds by education and gender (Italians with tertiary education are used as the standard)

	Males			Females		
	Low Ed.	*Med. Ed.*	*High Ed.*	*Low Ed.*	*Med. Ed.*	*High Ed.*
Eastern Europe						
Bulgaria	65.43	57.95	55.70	60.66	56.51	55.33
Croatia	60.08	58.22	53.98	56.32	56.90	53.86
Czech Republic	66.64	56.92	52.59	56.15	55.33	52.76
Estonia	66.11	59.10	55.60	58.44	55.80	52.53
FYR Macedonia	60.84	58.12	54.67	59.32	57.83	55.85
Hungary	66.74	58.05	55.77	59.36	55.73	55.39
Poland	61.95	58.49	53.97	56.27	55.16	53.25
Romania	63.97	58.52	57.09	58.76	56.57	55.97
Slovenia	60.45	54.52	51.90	54.64	52.22	51.32
Average	63.58	57.77	54.58	57.77	55.78	54.03
std. dev.	2.78	1.35	1.65	1.98	1.58	1.68
Western Europe						
Denmark	56.82	54.78	52.77	56.27	54.30	53.33
Finland	56.02	54.75	52.20	53.56	52.40	51.56
Italy	53.99	50.15	50.00	52.19	50.16	50.00
Malta	54.48	54.00	52.22	53.94	53.85	52.23
Norway	55.48	52.85	50.95	54.25	52.49	51.61
Portugal	55.04	53.84	52.98	53.25	52.72	52.56
Sweden	53.74	52.56	51.08	53.82	52.69	51.61
Average	55.08	53.28	51.74	53.90	52.66	51.84
std. dev.	1.11	1.62	1.09	1.24	1.32	1.04

Source: Sanderson and Scherbov (2016), Table 2.

the Eurostat dataset, these Italians generally had the highest life expectancies. The parameter that varies is r. This parameter can stand for any of the 96 possible life tables (16 countries, by two genders and by three educational categories). The alpha-ages that are calculated in this way are the ages of Italians with at least some tertiary education who have the same remaining life expectancy as 50-year-olds in one of the 96 possible life tables, r. Since Italians with at least some tertiary education had the highest remaining life expectancies, all of the remaining life expectancies at age 50 will be lower than those for the more educated 50-year-olds Italians, and the calculated alpha-ages will all be above 50.

In Table 5, the average alpha-ages of 50-year-old men and women with higher levels of education in the Western European countries were 51.74 and 51.84, respectively. The average size of the gaps between these average ages and those of the more educated Italians was less than two years. The average alpha-ages of 50-year-old men and women with higher levels of education in the Eastern European countries were 54.58 and 54.03, respectively. The gender differences for people in the highest educational group is small in both regions. In contrast, the gender differences in the average alpha-ages of people in the lowest educational group are much larger in the Eastern European countries than in the Western European countries. In that educational group, the mean alpha-age of women in the Western European countries was 53.90, and the corresponding figure for men was only 1.18 years higher. In the Eastern European countries, the mean alpha-age of less educated women was 57.77, and the corresponding figure for men was 5.81 years higher. Using alpha-ages allows for very natural quantifications of subgroup differences such as these. A more detailed discussion of these difference can be found in Sanderson and Scherbov (2016).

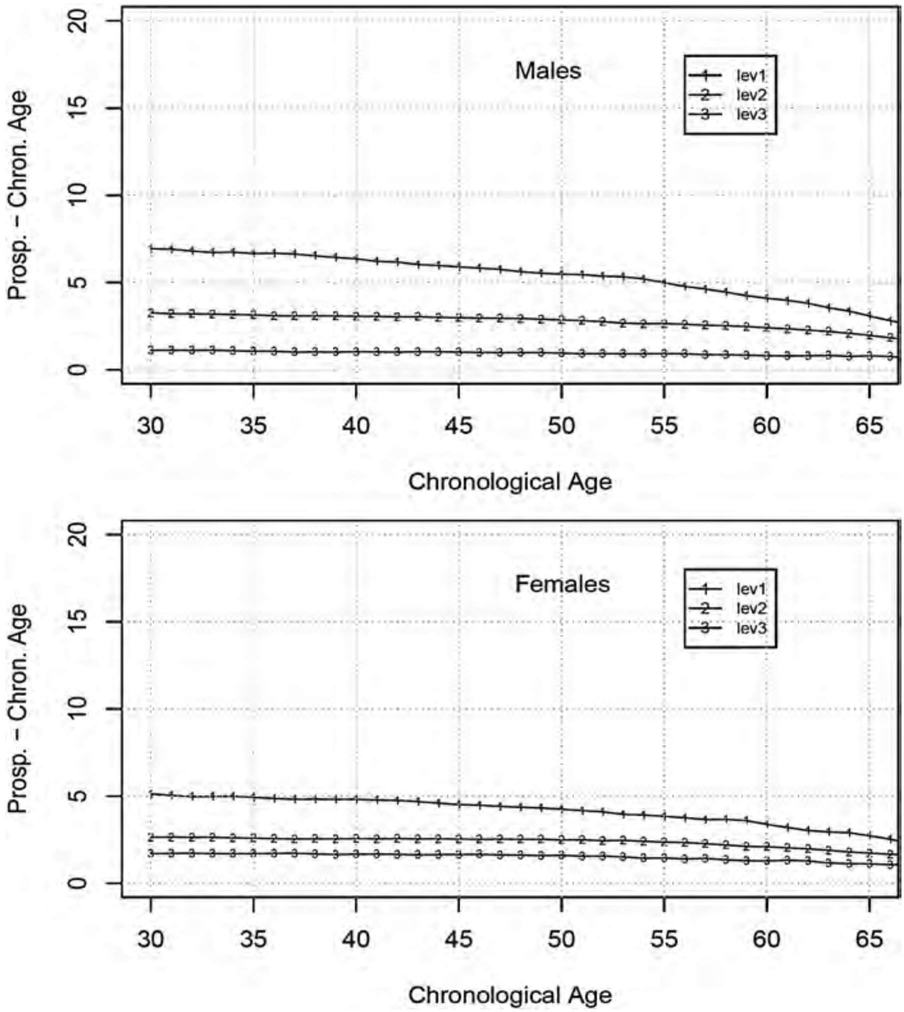
3.4 Example 4: Age difference trajectories by educational subgroups

In Example 4, we utilize a new concept that we call "age difference trajectories." Age difference trajectories are the relationships between chronological age, on the one hand; and the difference between the alpha-age and the chronological age, on the other. The trajectories do not show how fast a subgroup ages in an absolute sense, only how well a particular subgroup is doing at each chronological age relative to a reference subgroup. As before, our reference subgroup here consists of Italians with high education.

Example 4:
Age difference trajectories by sex and education – Figures 1–4
$\boldsymbol{C_s^{-1}(C_r(a)) - a = \alpha - a}$

Characteristic ($\boldsymbol{C}$( ))	**Remaining life expectancy**
Constant Parameters	***r* and *s*** *r* is any one of the set of 16 European life tables (see Table 5) by sex and level of education (latest available year), *s* is a sex-specific life table for Italians with at least some tertiary education
Variable Parameters	***a*** *a* is a set of ages between 30 and 66

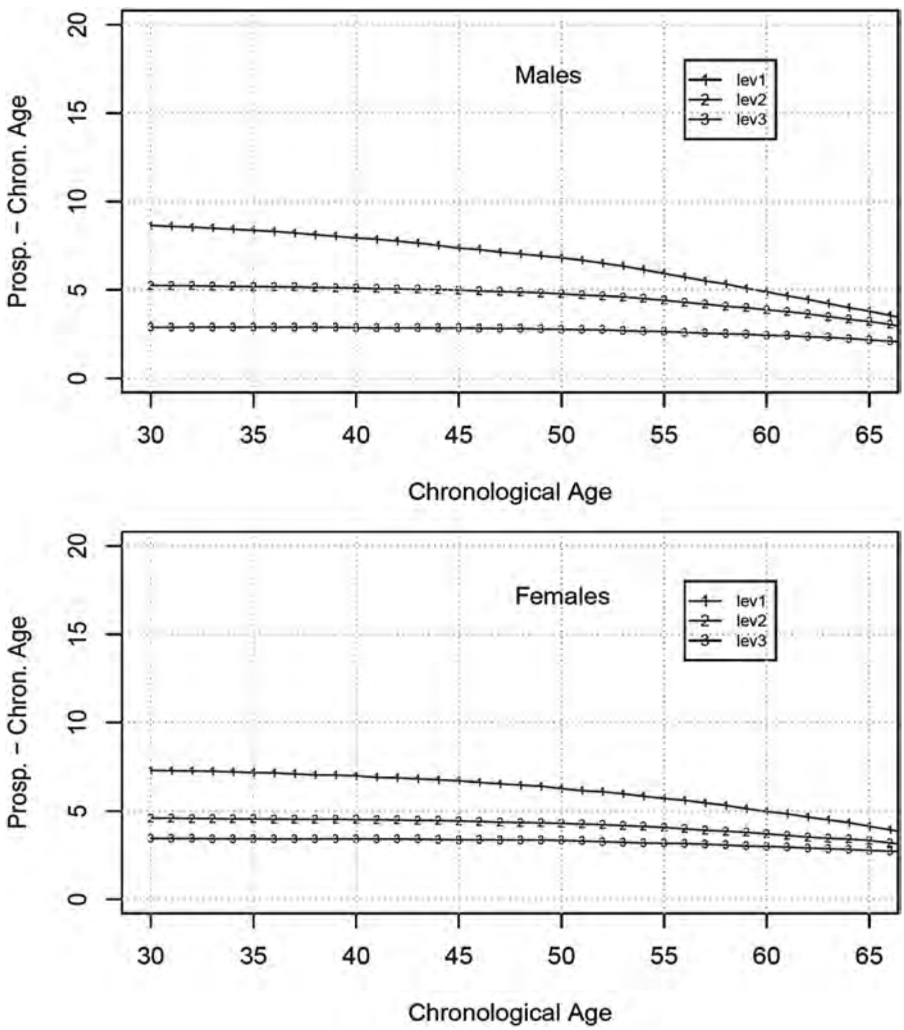
Figure 1:
Age difference trajectories, Norway, 2010 by level of education



Note: The characteristic is the remaining life expectancy at each age. The standard schedule is for Italians with tertiary education. lev1 refers to people with pre-primary, primary, and lower secondary education (ISCED 0, 1, and 2); lev2 refers to people with upper secondary and post non-tertiary education (ISCED 3 and 4); lev 3 refers to people with tertiary education (ISCED 5 and 6).
Source: Authors' calculations.

In Figures 1 through 4, we plot chronological age on the x-axis, and the difference between prospective age and chronological age on the y-axis. In other words, chronological age, a, is on the x-axis; and $\alpha - a$ is on the y-axis. The difference between prospective age and chronological age is a measure of the extent to which

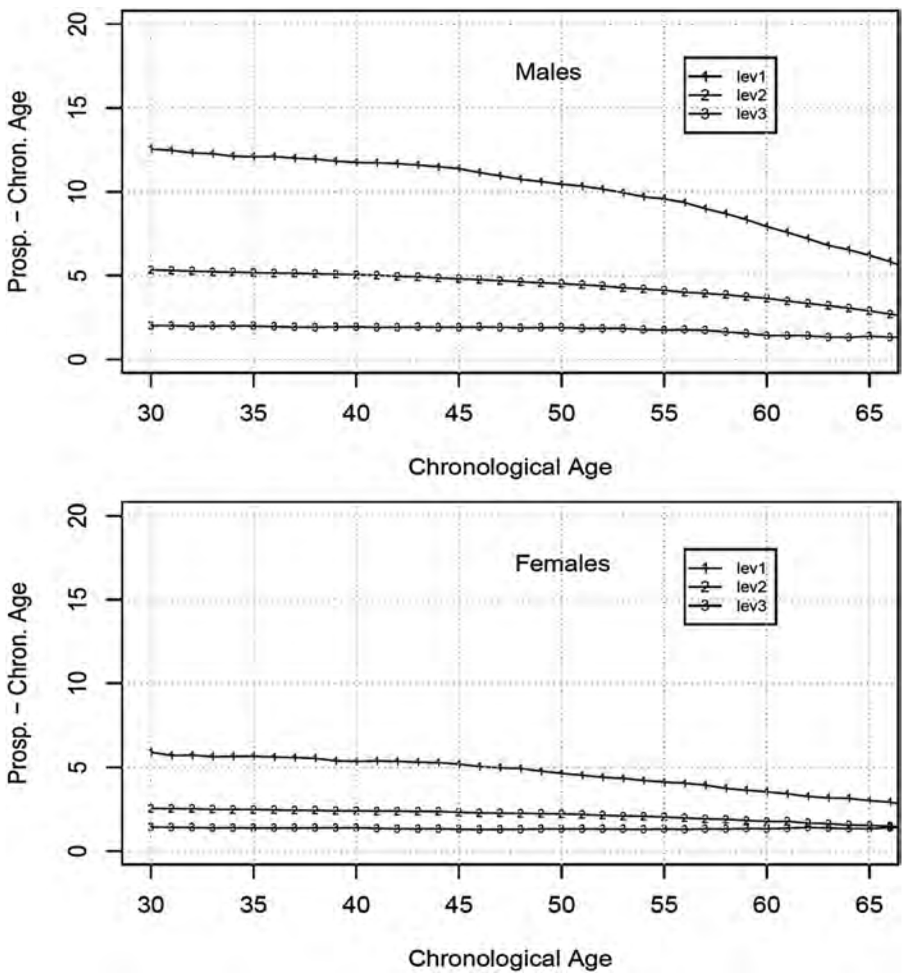
Figure 2:
Age difference trajectories, Denmark, 2010 by level of education



Note: The characteristic is the remaining life expectancy at each age. The standard schedule is for Italians with tertiary education. lev1 refers to people with pre-primary, primary, and lower secondary education (ISCED 0, 1, and 2); lev2 refers to people with upper secondary and post non-tertiary education (ISCED 3 and 4); lev 3 refers to people with tertiary education (ISCED 5 and 6).
Source: Authors' calculations.

the subgroup lags behind the Italians with high education. These age difference trajectories translate differences in patterns of life expectancies over ages into a form that is easy to visualize, interpret, and analyze. Because age difference trajectories

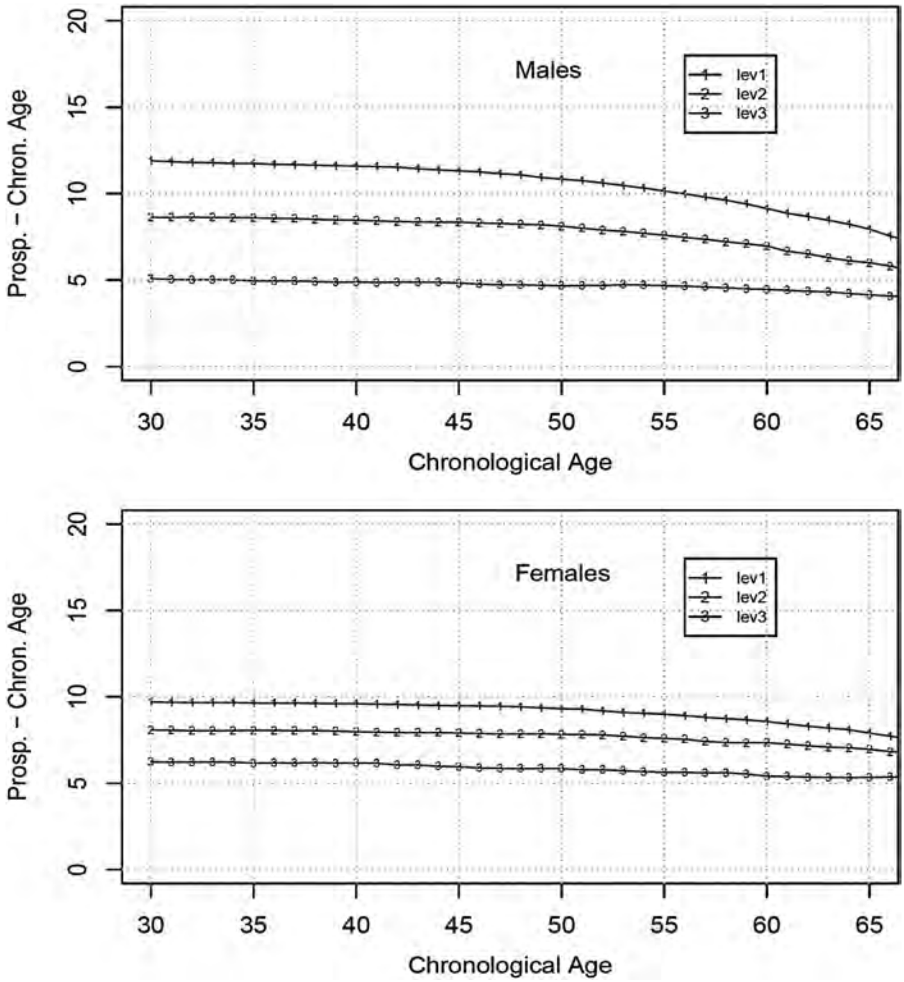
Figure 3:
Age difference trajectories, Slovenia, 2010 by level of education



Note: The characteristic is the remaining life expectancy at each age. The standard schedule is for Italians with tertiary education. lev1 refers to people with pre-primary, primary, and lower secondary education (ISCED 0, 1, and 2); lev2 refers to people with upper secondary and post non-tertiary education (ISCED 3 and 4); lev 3 refers to people with tertiary education (ISCED 5 and 6).
Source: Authors' calculations.

are relationships across ages, we can analyze how those trajectories differ in terms of both their levels and their slopes. Differences in levels tell us how far behind the subgroup is, while differences in slopes tell us whether the group is getting closer to or further from the reference group with increasing chronological age.

Figure 4:
Age difference trajectories, Macedonia, 2010 by level of education



Note: The characteristic is the remaining life expectancy at each age. The standard schedule is for Italians with tertiary education. lev1 refers to people with pre-primary, primary, and lower secondary education (ISCED 0, 1, and 2); lev2 refers to people with upper secondary and post non-tertiary education (ISCED 3 and 4); lev 3 refers to people with tertiary education (ISCED 5 and 6).
Source: Authors' calculations.

Figures 1 and 2 display the age difference trajectories for two Western European countries that have a common history: Norway and Denmark. Figures 3 and 4 show the age difference trajectories of two Eastern European countries that have a common history: (FYR) Macedonia and Slovenia. Italians with high education in 2009 are the reference group, *s*, from which all alpha-ages are computed. Each figure has three lines. The lines labeled 1, 2, and 3 refer to the respective trajectories for people with low, medium, and high educational attainment.

Norway is a country with a high life expectancy and a high per capita income. Even there, however, we see that, for men at age 30 with low education, the gap between the prospective and the chronological age is around seven years. We can see from the figure that the slope of the trajectory for less educated men is negative, which indicates that there is some degree of convergence toward the Italian standard with increasing chronological age. Norwegian men with high education have trajectories that are only slightly above zero, which indicates that they are similar to Italian men with high education at all ages. The trajectories for Norwegian women are similar, albeit with smaller differences across educational groups. The general patterns of the trajectories for Danish men and women are similar to those of their Norwegian counterparts, with the graphs for all three levels of education shifted upward by about three years. It is likely that this difference is due to differences in rates of smoking and alcohol consumption (Christensen et al. 2010).

Figure 3 shows the trajectories for Slovenia. Slovenian men and women with high education have age difference trajectories with slopes of approximately zero. Both of those trajectories are lower than those of their Danish counterparts, which indicates that they are closer to the trajectories of the Italian leaders. Slovenian men with medium education have trajectories that are almost identical to those of their Danish counterparts, while Slovenian women with medium education have trajectories that are clearly lower than those of their Danish counterparts. Slovenian women with low education also have lower trajectories than Danish women with low education. In all of the groups, except for the group of men with low education, Slovenians have age difference trajectories that are lower than those of their Danish counterparts. The situation of the Macedonians (see Figure 4) is quite different from those of the people in the other three countries. The trajectories for Macedonian women in all three age groups are comparatively high, and there is much less convergence with age across the educational subgroups. For Macedonian men, the high levels of the trajectories for those with medium and high education stand out.

4 Health- and disability-based ages and measures

Health is difficult to quantify, in part because it has so many dimensions, and in part because some of those dimensions are necessarily subjective. One rough approximation to health on a population level is the probability of surviving for the next five years. This characteristic has two advantages: (1) it can be measured or estimated reasonably accurately, and (2) it is comparable over time and place. Using the probability of surviving for the next five years as the characteristic of interest, we can calculate health-based age difference trajectories.

Example 5:
Survival-based age difference trajectories for countries – Figure 5 (own country standards)
$\boldsymbol{C_s^{-1}(C_r(a)) - a = \alpha - a}$

Characteristic ($C(\,)$)	**Probability of surviving for the next five years (l_{x+5}/l_x)**
Constant Parameters	***s*** *s* is a sex-specific life table for the country of interest in 2000
Variable Parameters	***a* and *r*** *a* is a set of ages between 40 and 80, *r* is one of a set of sex-specific life tables for the country of interest for the years 1953, 1960, 1970,. . . , 2010

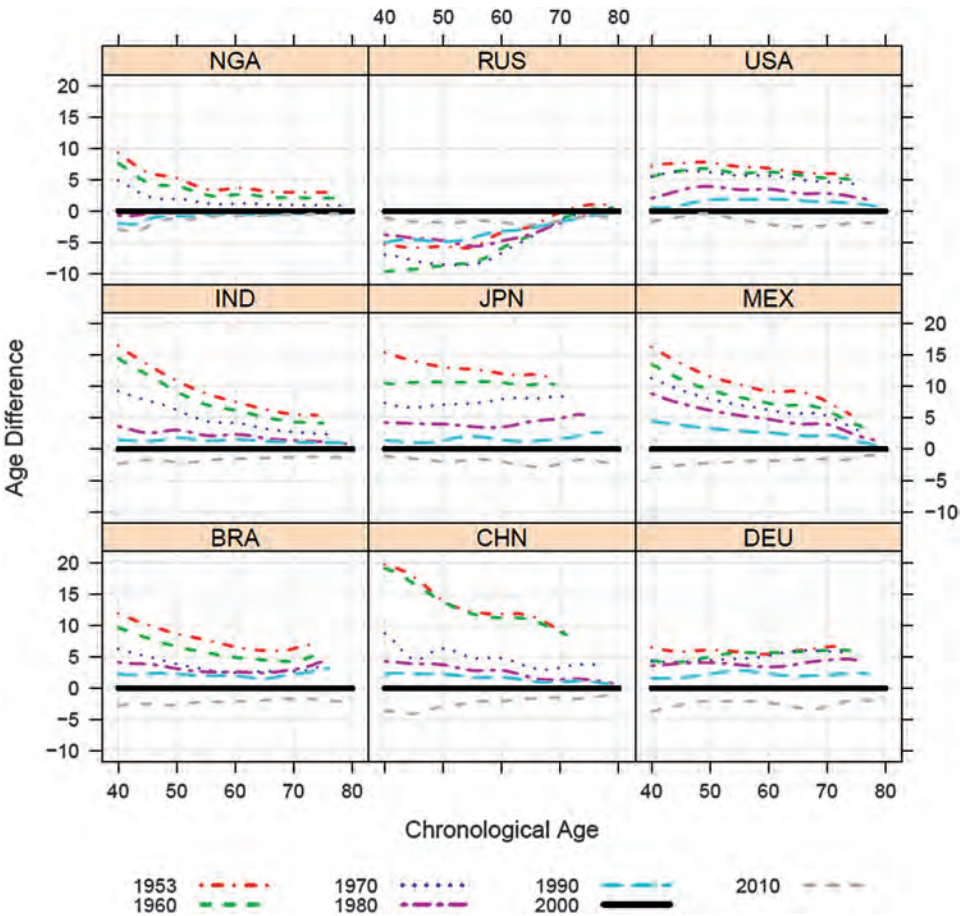
Example 6:
Survival-based age difference trajectories for countries – Figure 6 (Japan in 2010 as a standard)
$\boldsymbol{C_s^{-1}(C_r(a)) - a = \alpha - a}$

Characteristic ($C(\,)$)	**Probability of surviving for the next five years (l_{x+5}/l_x)**
Constant Parameters	***s*** *s* is a sex-specific life table for Japan in 2000
Variable Parameters	***a* and *r*** *a* is a set of ages between 40 and 80, *r* is one of a set of sex-specific life tables for the country of interest for the years 1953, 1960, 1970, . . . , 2010

4.1 Examples 5 and 6: Survival-based age difference trajectories

Survival rate-based age difference trajectories are presented in Figure 5 for Brazil, China, Germany, India, Japan, Mexico, Nigeria, the Russian Federation, and the USA using life tables for 1953, and at 10-year intervals from 1960 through 2010. Country life tables for 2000 are used as standards *s*, and the differences between alpha-ages and chronological ages in 2000 are shown for ages 40 to 80. This example provides a visualization of the changes in the survival rates across ages and over time within countries. Two distinct patterns are evident. In the developing countries of Brazil, China, India, Mexico, and Nigeria, improvements in five-year survival rates have been faster at age 40 than at later ages. In China and India, in particular, large improvements in survival rates are seen after 1960. In Germany,

Figure 5:
Age difference trajectories, Brazil, China, Germany, India, Japan, Mexico, Nigeria, Russian Federation, and the USA for 1953, 1960, 1970, . . . , 2010

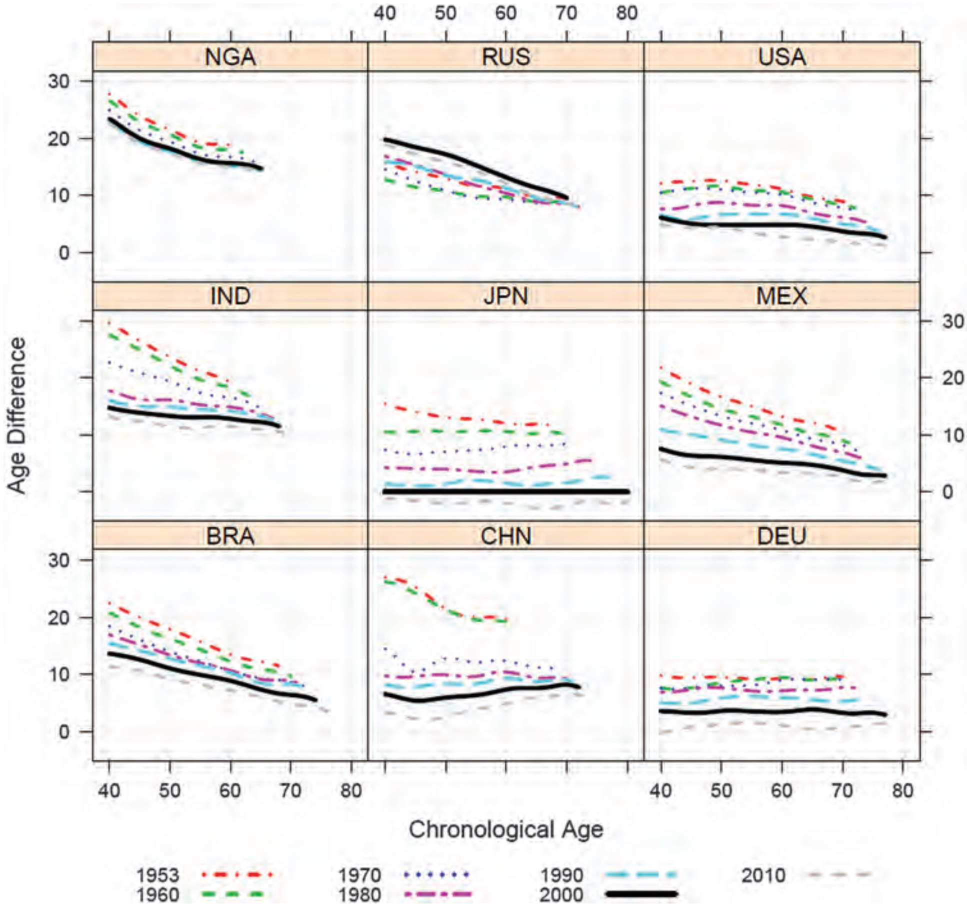


Note: Characteristic is the five-year survival rate at each age. The standard schedule, *s*, is the schedule for each country individually in 2000.
Source: Authors' calculations based on United Nations (2013b).

Japan, and the USA, the age trajectories in recent decades are roughly parallel lines that move downward over time. The graph for the Russian Federation is distinctly different, reflecting the effects of the mortality crisis after 1991.

Figure 6 shows the same survival rate-based trajectories using Japanese life tables in 2010 as the standard. Japan has some of the highest age-specific survival rates in the world. Age trajectories based on a single standard allow for the visualization of the evolution of age-specific survival rates for various ages relative to the

Figure 6:
Age difference trajectories, Brazil, China, Germany, India, Japan, Mexico, Nigeria, Russian Federation, and the USA for 1953, 1960, 1970, . . . , 2010



Note: Characteristic is the five-year survival rate at each age. The standard schedule, *s*, is for Japan in 2000.
Source: Authors' calculations based on United Nations (2013b).

corresponding rates of the world's leaders. For most countries, we see negatively sloped age trajectories that decline over time. In Germany, the age trajectories are nearly horizontal lines, which indicates that at each age, the survival rates have been changing in line with the Japanese standard rates. The age difference trajectory for the USA has a slightly negative slope, which indicates that the survival rates at younger ages are lower than those of the Japanese at older ages. The graph for the Russian Federation again reflects the mortality crisis in that country. In 2000, the survival rates at age 40 were lower in Russia than in any of the other nine countries shown except for Nigeria. The pattern for Japan itself is worth noting. From 1990 through 2010, the changes in the trajectory have been greater for people aged 60 and older than for people below age 60. It will be interesting to see whether this pattern persists.

The pattern that is observed for China is distinctly different. In the data for 2000 and 2010, there is a distinctly positive slope in the trajectory, which indicates that when looking across ages, the Chinese survival rates have become progressively worse relative to those in Japan. This points to an issue that bears further investigation.

Example 7:
Alpha-ages based on proportions in self-reported good (bad) health
$\boldsymbol{\alpha = C_s^{-1}(C_r(a))}$

Characteristic (*C*( ))	Proportion of population in self-reported good (bad) health
Constant	***s***
Parameters	*s* is the age-specific proportion of people in self-reported good (bad) health in the EU-15 in 2007
Variable Parameters	***a* and *r*** *a* is a set of ages between 20 and 84, *r* is the age-specific proportion of people in self-reported good (bad) health in the EU-15 in 2011.

4.2 Example 7: Alpha-ages of those in good and in bad self-reported health

The age-specific schedules of prevalence rates of health conditions quite naturally fall within the unifying framework presented here. For example, the age-specific proportions of European populations with three levels of self-reported health are available for European countries. To illustrate how these data can be used, characteristic schedules for the proportions of the population of the EU-15 in good self-reported health and in bad self-reported health were computed by sex for 2007 and 2011; the earliest and the latest years available at the time of writing ("EurOhex" 2015). Data on the proportions by five-year age groups were turned into characteristic schedules using linear regressions with observations set at the midpoints of age intervals using age, age squared, and a dummy variable for the year 2011 as independent variables. For each gender, alpha-ages were computed separately for proportions with good self-reported health and with bad self-reported heath. Women aged 61.6 had the same level of self-reported good health in 2011 as their 60-year-old counterparts had in 2007. Meanwhile, women aged 62.2 had the same level of self-reported bad health in 2011 as their 60-year-old counterparts had in 2007. For men, the results were similar: over the period 2007 to 2011, there was a gain of roughly two years in alpha-ages for 60-year-olds using self-reported health as the characteristic. Demuru (2017) adjusted the prospective ages in Italy using survey data on self-reported health.

5 Biomarker-based ages

Surveys such as the Health and Retirement Study (HRS) and its sister surveys measure a wide range of population characteristics. Some of these characteristics are measured using self-reports, such as the age-specific proportions of people in good self-reported health, the subjective probabilities of surviving to some future age, and self-reports on disabilities and difficulties in accomplishing specific tasks. Other observations are based on various sorts of objective measurements, which can be divided into the following categories: (1) measurements of physical performance, such as hand grip strength, walking speed, speed of standing up from a sitting position, and the length of time a person can keep his balance in a certain position; (2) measurements of mental performance, such as immediate word recall, delayed word recall, the ability to subtract seven sequentially beginning with 100, and verbal fluency; and (3) measurements of body chemistry, such as those derived from saliva and blood tests.

Example 8:
Alpha-ages of population subgroups based on hand grip strength – Table 6
$\boldsymbol{\alpha = C_s^{-1}(C_r(a))}$

Characteristic ($\boldsymbol{C}$( ))	**Hand grip strength**
Constant Parameters	***r* and *s*** *r* is the age-specific hand grip strength of people in a specific gender and race group with more education *s* is the age-specific hand grip strength of people in a specific gender and race group with less education
Variable Parameters	***a*** *a* is a set of ages between 60 and 80

Table 6:
Alpha-ages based on hand grip strength for population subgroups

Reference age of less educated	Whites – more educated		African Americans – more educated	
	Male	Female	Male	Female
60	65.8 (63.9, 67.7)	65.7 (63.9, 67.3)	57.6 (53.4, 61.4)	64.7 (60.5, 68.2)
65	69.6 (68.2, 70.9)	69.4 (68.2, 70.7)	63.4 (60.3, 66.3)	68.5 (65.3, 71.3)
70	73.4 (72.3, 74.5)	73.3 (72.3, 74.3)	69.2 (66.5, 71.6)	72.3 (69.5, 74,8)
75	77.3 (76.4, 78.3)	77.2 (76.4, 78.1)	74.7 (71.9, 77.6)	76.1 (73.3, 79.0)
80	81.3 (80.2, 82.3)	81.2 (80.2, 82.2)	80.3 (76.9, 83.9)	80.0 (76.5, 83.7)

Source: Sanderson and Scherbov (2014), Table 1.
Note: Figures in parentheses show the 95-percent confidence intervals.

5.1 Example 8: Alpha-ages of population subgroups based on hand grip strength

Integrating this plethora of observations of different characteristics of people into a consistent picture of the aging process is a challenge. The concept of alpha-ages can be useful in this context, as different characteristics can be translated into alpha-ages that can be readily compared. For example, alpha-ages based on the characteristic of hand grip strength can be used to study the differences in the speed of aging among educational subgroups in the United States. Hand grip strength has been shown to be a predictor of subsequent mortality and morbidity (Leong et al. 2015; Al Snih et al. 2002; Ambrasat, Schupp and Wagner 2011).

In Sanderson and Scherbov (2014), we combined data from the 2006, 2008, 2010, and 2012 waves of the Health and Retirement Survey (HRS) on the hand grip strength levels of men and women aged 60 to 80 by race and level of education. Two educational groups were distinguished: those with less than a completed high school education and those with a completed high school education or more. Four characteristic schedules were created from these data (two genders cross-classified by two racial groups) using regressions with individual fixed effects, controlling for age, height, weight, and HRS wave.

The results are shown in Table 6. Hand grip strength increases with the level of education for both men and women. If we turn hand grip strength levels into alpha-ages, we can see, for example, that on average, the 69.4-year-old white women in the higher educational group have the same hand grip strength levels as the 65-year-old women in the lower educational group. Using hand grip strength as the characteristic, we can observe that more educated white women aged less rapidly than less educated white women, as the former group had the same average hand grip strength level as the latter group more than four years later in life. A wide variety of measures of physical and mental performance can be analyzed in the same way.

5.2 Alpha-age and biological age

Biological age is usually measured by combining blood- and saliva-based observations. Such measurements can be easily performed using alpha-ages. In a recent paper (Levine and Crimmins 2014), three biomarker-based measures – namely, the allostatic load, the Framingham risk score, and the so-called “biological age” – were assessed to determine which one is the best predictor of subsequent 10-year mortality. Using 9,042 observations from the National Health and Nutrition Examination Survey III, Levine and Crimmins found that biological age was the best predictor. It is based on an index of nine individual observations: CRP, serum creatinine, Hba1c, albumin, total cholesterol, CMV, alkaline phosphatase, FEV1, urea nitrogen, and systolic blood pressure. All but the last of these observations are based on blood tests.

The methodology for the construction of biological age depends on two parameters for each of the biomarkers: namely, the constant term and the slope of the relationship between the biomarker and chronological age. Using the terminology in this paper, we have based our definition of biological age on nine characteristic functions. This methodology could represent a new approach to computing biological age. For each individual, alpha-ages are computed for a set of relevant characteristics, and are then combined. This approach could be used in the future as a simple and straightforward way of calculating biological age, especially as it makes it easy to test the relative importance of each of the biomarkers in forecasting mortality. The relationship between biomarkers and aging has also been studied in Rehkopf et al. (2017).

6 Alpha-ages as intergenerationally equitable normal pension ages

Up to this point, we have focused on the age-specific characteristics of people that are relevant for the study of population aging. We have provided examples in which we translated into alpha-ages characteristics as different as hand grip strength, five-year survival rates, remaining life expectancy, and self-reported health. Population aging is a multidimensional phenomenon, and the use of alpha-ages allows us to study those characteristics in a unified framework. In this section, we show how the range of applications of alpha-ages can be extended to the formulation of public policy.

The setting of normal pension ages is an important public policy decision. In almost all OECD countries, normal pension ages (or arrangements that have a similar effect) are currently being increased (OECD 2014, 2013, 2011). However, the rationale for such increases is often muddled. It is sometimes argued that normal pension ages must rise because governments would otherwise face severe fiscal difficulties. This rationale is unconvincing, and proposals to raise the normal pension age on the basis of such arguments tend to generate substantial public resistance. If the maintenance of current pension arrangements is considered socially desirable, then governments could raise the money to fund these pensions from a wide variety of sources, including higher taxes, lower expenditures on other activities, and improvements in the efficiency of the provision of public services. There is no particular reason why the people who are looking forward to receiving a pension should bear most of the burden of solving the government's fiscal problems. Raising the normal pension age just because pensions are expensive is a bit like reducing the number of schools because education is expensive.

In a situation in which life expectancy at older ages is growing, the maintenance of a fixed normal pension age is not socially desirable, because it results in intergenerational inequality. Thus, in such policy discussions, it is useful to have a simple and equitable benchmark that is easy to interpret, and that can be used to compare planned and potential increases in normal pension ages.

In Sanderson and Scherbov (2015), we formulated a simple example in which we produced an intergenerationally equitable normal pension age based on three principles: (1) the members of each cohort should receive pension benefit amounts equal to their contributions, (2) the generosity of the pension system (the ratio of the average pension benefit to the average income of those who contribute to the pension system, after the pension tax) should remain constant across cohorts, and (3) the pension tax rate should remain constant across cohorts. Combining these principles results in a simple condition that an intergenerationally equitable normal pension age must meet. The ratio of person-years lived from the normal pension age onward to the number of person-years lived from the age of labor market entry onward must be constant. In life table notation $\frac{T_{pen}}{T_{lme}} = K$, where *pen* is the normal pension age, *lme* is the age of labor market entry, and K is a constant. Different values of K arise from different combinations of pension generosity and the pension tax rate.

6.1 Example 9: Alpha-ages and normal pension ages

The alpha-ages that hold the proportion of adult person-years lived receiving a public pension constant at the level observed at age 65 in 2013 in Germany are shown in Table 7 for selected European countries for the years 2013, 2020, 2030, 2040, and 2050. Using a single country as a standard allows us to see what an intergenerationally equitable pension age would be if the ratio of person-years with a pension to total adult person-years was the same in all countries. In 2050, if the proportion of adult person-years spent with a pension are projected to be the same as they were for 65-year-olds in Germany in 2013, the normal pension age would have to be around 71 in France, 69 in the UK, 67 in Latvia, 66 in Bulgaria, 64 in the Russian Federation, and almost 70 in Germany itself.

Under current legislation, the normal pension age is on track to rise to 67 by 2029 in Germany, and to around 69 in the UK in the 2040s. These ages are very close

Example 9:
Alpha-ages as normal pension ages – Table 7 (German 2013 basis)
$\alpha = C_s^{-1}(C_r(a))$

Characteristic ($C(\,)$)	**Proportion of adult person-years lived after age $a(T_a/T_{20})$**
Constant Parameters	***a* and *r*** *a* is age 65, *r* is the characteristic schedule for Germans in 2013 (both sexes combined)
Variable Parameters	***s*** *s* is a set of similar characteristic schedules in selected European countries in the years 2013, 2020, 2040, and 2050.

Table 7:
Intergenerationally equitable normal pension ages

German basis Country	**2013**	**2020**	**2030**	**2040**	**2050**
Bulgaria	61.03	61.51	62.74	63.96	65.25
France	66.40	67.26	68.60	69.81	71.08
Georgia	61.44	62.13	63.36	64.59	65.85
Germany	65.00	65.91	67.26	68.51	69.80
Greece	64.95	66.02	67.39	68.65	69.95
Ireland	65.06	65.68	66.84	68.04	69.26
Italy	66.09	66.70	67.97	69.26	70.53
Latvia	61.09	61.93	63.27	64.62	65.90
Russian Federation	59.43	59.89	61.16	62.34	63.53
Serbia	61.05	61.81	63.05	64.28	65.54
Slovakia	62.05	62.87	64.21	65.50	66.81
Spain	65.92	66.42	67.76	69.03	70.31
Sweden	65.43	66.10	67.32	68.55	69.81
United Kingdom	65.23	65.86	67.13	68.33	69.56

Note: The standard schedule, *s*, is for Germany in 2013, where the normal pension age is set equal to 65.
Source: Authors' calculations, see Sanderson and Scherbov (2015).

to the figures in Table 7. A more complete discussion of the relationship between the planned and the forecasted alpha-age-based normal pension ages can be found in Sanderson and Scherbov (2015). That paper also includes a discussion of the relationship between the alpha-age-based normal pension ages and the pension ages in the notional defined contribution pension plans.

Instead of legislating incremental increases in normal pension ages in piecemeal fashion, it would be simpler to adopt a policy based on alpha-ages. An alpha-age-based pension age policy would have three important advantages. First, while future increases in life expectancy are uncertain. An alpha-age based policy would automatically adjust for changes in life expectancy. Second, as countries age it could become increasingly difficult to enact pension age changes that are consistent with intergenerational equity. A pension age policy based on alpha-ages would make those changes without repeated contentious political debates. Third, and perhaps most importantly, alpha-age based pension ages are intergenerationally equitable. The rationale for changing normal pension ages should not be that the government is running out of money, but rather that normal pension ages should be set on the basis of fairness.

7 Related ages

7.1 Thanatological age

The idea of thanatological age was introduced in Brouard (1986), and more recently there has been increased interest in the concept because of its relationship to health care costs (Miller 2001; Lubitz et al. 2003; Yang, Norton and Stearns 2003; Payne et al. 2007). Whereas chronological age is the exact number of years a person has already lived, thanatological age is the exact number of years a person has left to live. From conventional life tables, it is possible to create both thanatological life tables and thanatological characteristic schedules. One possible thanatological characteristic schedule would relate thanatological age and the average age of people who had specific numbers of years left to live. One interesting use of a thanatological life table would be to look at the proportion of the population who had five or fewer years of remaining life.

Up to this point, we have interpreted $C_r(a)$ as the relationship between a characteristic and chronological age in characteristic schedule r. It is possible to use the same formulation with thanatological age instead of chronological age. For clarity, we express the relationship between a characteristic and thanatological age as $D_r(b)$, where b is a thanatological age.

Alpha-ages are derived from the equation:

$$\alpha = C_s^{-1}(C_r(a)).$$

Beta-ages are the analogous numbers based on thanatological ages rather than chronological ages.

$$\beta = D_s^{-1}(D_r(b)).$$

Riffe et al. (2017) showed how thanatological age and prospective age can be used together to study how populations age.

7.2 Anticipated longevity

Many surveys of older populations (such as HRS, SHARE, ELSA) include questions in which participants are asked to anticipate their longevity. Responses to these questions have been used to calculate anticipated life expectancy. Anticipated life expectancy is a characteristic that can be analyzed using alpha-ages. This has been done in Aktas and Sanderson (2015), in which estimates from anticipated life tables were transformed into anticipatory ages. Palloni and Novak (2017) showed that subjective life tables and observed life tables are consistent with each other.

8 Technical considerations

Computing alpha-ages involves inverting continuous and monotonic characteristic schedules. In practice, characteristic schedules are often not continuous. For example, life tables provide life expectancies for people at their 60th and 61st birthdays, but not when they are 60 years and 6 months old. This problem is easily solved by interpolating the unobserved values of characteristics between chronological ages. Characteristic schedules also need not always be monotonic. In this were the case, we would only study those portions of the schedules the are monotonic. In this paper, the problem of non-monotonicity never arose.

All of the forecasts of aging in this paper are based on forecasts of life tables produced either for the European Demographic Datasheet (VID 2014) or by the United Nations (2013b). The methodologies for forecasting life tables are well understood. Life expectancies are projected to increase slightly faster in the European Demographic Datasheet than in the United Nations estimates. Life table forecasts can also be used to compute more complex forecasts based on the Sullivan method (Sullivan 1971). In that method, age-specific characteristics, such as being without a severe disability, are applied to life tables. This approach can be used to forecast healthy life expectancies, assuming that the age-specific prevalence of the characteristic does not change.

Characteristic schedules are uncertain. Especially in cases in which the degree of uncertainty is not trivial, it is important to compute it precisely, and to include it in the analysis. We do this in the discussion of alpha-ages based on hand grip strength (see Example 8).

9 Concluding discussion

There is a common narrative that population aging will lead to serious fiscal challenges. This argument is based on the observation that the ratio of people aged 65 and older to people aged 15 to 64 is rising dramatically in many countries. It is generally expected that the older group will be dependent on the younger group for their pensions and health care, and that the resulting increases in taxes on the young to finance those expenditures will reduce their incentives to work and save, thereby reducing economic growth.

Fortunately, this narrative is largely wrong. Normal pension ages are in the process of changing. A number of the countries that once had a normal pension age of 65 have since raised this age. In many OECD countries, normal pension ages are scheduled to increase to 67 and even higher in the next few decades. In addition to changes in normal pension ages, there have been numerous changes in pension eligibility rules, which have an effect similar to that of raising the normal pension age (OECD 2014, 2013, 2011). Analyzing the fiscal problems of population aging based on the assumption that the normal pension ages will remain fixed at 65 is incorrect and misleading.

A similar sort of problem arises with the interpretation of age 65 as the age at which people begin to have significantly higher medical expenses. First, health care expenditures are concentrated in the last few years of life (Miller 2001; Lubitz et al. 2003; Yang, Norton and Stearns 2003; Payne et al. 2007). With increases in life expectancy, those last few years of life are gradually postponed. Ignoring increases in life expectancy produces estimates of health care costs that rise too rapidly. Second, life expectancy without severe disabilities is rising with increases in life expectancy, and the onset of severe disabilities is also being postponed (Sanderson and Scherbov 2010). Ignoring this trend also produces an upward bias in estimates of the burden that the elderly will impose on younger people.

Since the narrative of the rapid increase in the burdens associated with population aging is so transparently biased, it is interesting to ask why it is so common. One reason, we suspect, is that policy-makers, journalists, and others interested in population aging have not had easy access to measures of population aging that take into account the changing characteristics of the population. In this paper and in earlier ones, we have provided easy-to-use measures that offer a different and more realistic narrative.

However, alpha-ages provide more than just better aggregate measures of population aging; they provide a methodology for translating characteristics that are measured in very different units into a common metric. This unification process allows for the construction of composite measures of population that are easy to understand and interpret. In other words, alpha-ages provide us with the ability to study the multidimensional phenomenon of population aging using appropriate multidimensional indices. Furthermore, as an example of the applicability of this approach to public policy, we have also shown how alpha-ages can be used to produce an analytically-based, intergenerationally equitable normal pension age.

Population aging in the 21st century cannot be adequately studied using tools that do not take into account the changing characteristics of the population. The older tools were developed in an era when the relevant characteristics of people were changing relatively slowly. As this is no longer the case, the scientific study of population aging and policy formulation should no longer be based on those tools. Using alpha-ages, it is now possible to study 21st century population aging with appropriate 21st century tools.

Acknowledgements

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References

Aktas, Arda and Warren C. Sanderson 2015. A forward looking age based on longevity expectations. IIASA Interim Report IR-15-016. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA). http://pure.iiasa.ac.at/11673/1/IR-15-016.pdf.

Al Snih, Soham, Kyriakos S. Markides, Kenneth J. Ottenbacher and Mukaila A. Raji 2004. Hand grip strength and incident ADL disability in elderly Mexican Americans over a seven-year period. *Aging Clinical and Experimental Research* 16 (6): 481–86. doi:10.1007/BF03327406.

Al Snih, Soham, Kyriakos S. Markides, Laura Ray, Glenn V. Ostir and James S. Goodwin 2002. Handgrip strength and mortality in older Mexican Americans. *Journal of the American Geriatrics Society* 50 (7): 1250–1256. doi:10.1046/j.1532-5415.2002.50312.x.

Ambrasat, Jens, Jürgen Schupp and Gert G. Wagner 2011. Comparing the predictive power of subjective and objective health indicators: Changes in hand grip strength and overall satisfaction with life as predictors of mortality. *SOEPpapers on Multidisciplinary Panel Data Research* 398.

Brouard, Nicolas 1986. Structure et dynamique des populations. La pyramide des années à vivre, aspects nationaux et exemples régionaux. *Espace, Populations, Sociétés* 4(2): 157–68. doi:10.3406/espos.1986.1120.

Christensen, Kaare, Michael Davidsen, Knud Juel, Laust Mortensen, Roland Rau and James W. Vaupel 2010. The divergent life-expectancy trends in Denmark and Sweden—and some potential explanations. http://www.ncbi.nlm.nih.gov/books/NBK62583/.

Demuru, Alberto 2017. Controlling prospective age for health status: How to rejuvenate the population by improving health. *Vienna Yearbook of Population Research* 2016 (forthcoming).

Emelyanova, Anastasia and Arja Rautio 2017. Population ageing dynamics in the North Atlantic region of the Arctic. *Vienna Yearbook of Population Research* 2016 (forthcoming).

EurOhex 2015. *Ja:EHLEIS Information System*. Accessed June 16. http://maryland.mri.cnrs.fr/ehleis/IS/index.php?controller=healthExpectancies/NationalHealths&action=displayDataForSPH.

Eurostat 2013. Life expectancy by age, sex, and educational attainment (ISCED 1997). European Union. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_mlexpecedu&lang=en.

Flynn, James R. 1987. Massive IQ gains in 14 nations: What IQ tests really measure. *Psychological Bulletin* 101(2): 171–91. doi:10.1037/0033-2909.101.2.171.

Habibi, Ehsanollah, Meghdad Kazemi, Habibollah Dehghan, Behzad Mahaki and Akbar Hassanzadeh 2013. Hand grip and pinch strength: Effects of workload, hand dominance, age, and body mass index. *Pakistan Journal of Medical Sciences* 29 (1, Suppl). doi:10.12669/pjms.291(Suppl).3535.

Innes, Ev 1999. Handgrip strength testing: A review of the literature. *Australian Occupational Therapy Journal* 46 (3): 120–140. doi:10.1046/j.1440-1630.1999.00182.x.

Leong, Darryl P, Koon K Teo, Sumathy Rangarajan, Patricio Lopez-Jaramillo, Alvaro Avezum Jr, Andres Orlandini, Pamela Seron, et al. 2015. Prognostic value of grip strength: Findings from the prospective urban rural epidemiology (PURE) study. *The Lancet*. doi:10.1016/S0140-6736(14)62000-6.

Levine, Morgan E. and Eileen M. Crimmins 2014. A Comparison of methods for assessing mortality risk. *American Journal of Human Biology* 26(6): 768–76. doi:10.1002/ajhb.22595.

Lubitz, James, Liming Cai, Ellen Kramarow and Harold Lentzner 2003. Health, life expectancy, and health care spending among the elderly. *New England Journal of Medicine* 349(11): 1048–55. doi:10.1056/NEJMsa020614.

Lutz, Wolfgang, Warren C. Sanderson and Sergei Scherbov 2008. The coming acceleration of global population ageing. *Nature* 451(7179): 716–19. doi:10.1038/nature06516.

Miller, Tim 2001. Increasing longevity and medicare expenditures. *Demography* 38(2): 215–26. doi:10.1353/dem.2001.0018.

OECD 2011. *Pensions at a glance 2011: Retirement-income systems in OECD and G20 countries*. Paris: OECD. http://www.oecd.org/berlin/publikationen/pensionsataglance2011retirement-incomesystemsinoecdundg20countries.htm.

OECD 2013. *Pensions at a glance 2013: Retirement-income systems in OECD and G20 countries*. Paris: OECD. http://www.oecd.org/pensions/pensionsataglance.htm.

OECD 2014. *OECD pensions outlook 2014*. Paris: OECD Publishing.

Palloni, Alberto and Beatriz Novak 2017. Subjective survival expectations and observed survival: How consistent are they? *Vienna Yearbook of Population Research* 2016 (forthcoming).

Payne, Greg, Audrey Laporte, Raisa Deber and Peter C. Coyte 2007. Counting backward to health care's future: Using time-to-death modeling to identify changes in end-of-life morbidity and the impact of aging on health care expenditures. *Milbank Quarterly* 85(2): 213–57. doi:10.1111/j.1468-0009.2007.00485.x.

Rehkopf, David, Luis Rosero-Bixby and William Dow 2017. A cross-national comparison of twelve biomarkers finds no universal biomarkers of aging. *Vienna Yearbook of Population Research* 2016 (forthcoming).

Riffe, Tim, Phil H. Chung, Jeroen Spijker and John MacInnes 2017. Time-to-death patterns in markers of age and dependency. *Vienna Yearbook of Population Research* 2016 (forthcoming).

Ryder, Norman B. 1975. Notes on stationary populations. *Population Index* 41(1): 3–28. doi:10.2307/2734140.

Sanderson, Warren C. and Sergei Scherbov 2005. Average remaining lifetimes can increase as human populations age. *Nature* 435(7043): 811–13. doi:10.1038/nature03593.

Sanderson, Warren C. and Sergei Scherbov 2007. A new perspective on population aging. *Demographic Research* 16 (January): 27–57. doi:10.4054/DemRes.2007.16.2.

Sanderson, Warren C. and Sergei Scherbov 2008a. Conventional and prospective measures of population aging, 1995, 2005, 2025, 2045. Population Reference Bureau. http://www.prb.org/excel08/age-ageing_table.xls.

Sanderson, Warren C. and Sergei Scherbov 2008b. Rethinking age and aging. Population Bulletin 63 4. Washington, D.C.: Population Reference Bureau. http://www.prb.org/pdf08/63.4aging.pdf.

Sanderson, Warren C. and Sergei Scherbov 2010. Remeasuring aging. *Science* 329 (5997): 1287–88. doi:10.1126/science.1193647.

Sanderson, Warren C. and Sergei Scherbov 2013. The characteristics approach to the measurement of population aging. *Population and Development Review* 39(4): 673–85. doi:10.1111/j.1728-4457.2013.00633.x.

Sanderson, Warren C. and Sergei Scherbov 2014. Measuring the speed of aging across population subgroups. *PLoS ONE* 9(5): e96289. doi:10.1371/journal.pone.0096289.

Sanderson, W. C. and S. Scherbov 2015. An easily understood and intergenerationally equitable normal pension age. In *The future of welfare in a global Europe*, ed. B. Marin, 193–220. Farnham, UK: Ashgate Publishing.

Sanderson, Warren C. and Sergei Scherbov 2016. A new perspective on patterns of aging in Europe by education and gender. *Journal of Population Ageing* 9(3): 207–225. doi:10.1007/s12062-015-9125-z.

Scherbov, Sergei and Warren C. Sanderson 2014. Prospective measures of population aging: Version 1.0, June, 2014. www.reaging.org/indicators.

Schneeweis, Nicole, Vegard Skirbekk and Rudolf Winter-Ebmer 2014. Does education improve cognitive performance four decades after school completion? *Demography* 51(2): 619–43. doi:10.1007/s13524-014-0281-1.

Skirbekk, Vegard, Elke Loichinger and Daniela Weber 2012. Variation in cognitive functioning as a refined approach to comparing aging across countries. *Proceedings of the National Academy of Sciences* 109(3): 770–74. doi:10.1073/pnas.1112173109.

Stoet, Gijsbert and David C. Geary 2013. Sex Differences in mathematics and reading achievement are inversely related: Within- and across-nation assessment of 10 years of PISA data. *PLoS ONE* 8(3): e57988. doi:10.1371/journal.pone.0057988.

Stojilkovic Gnjatovic, Jelena 2017. Some characteristics of population ageing using prospective approach: Serbia as case study. *Vienna Yearbook of Population Research* 2016 (forthcoming).

Sullivan, Daniel F. 1971. A single index of mortality and morbidity. *HSMHA Health Reports* 86(4): 347–54. doi:10.2307/4594169.

United Nations 2013a. World population ageing 2013. ST/ESA/SER.A/348. New York, USA: Department of Economic and Social Affairs, Population Division. http://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2013.pdf.

United Nations 2013b. World population prospects: The 2012 revision. New York, NY: Department of Economic and Social Affairs, Population Division. http://esa.un.org/wpp/Excel-Data/EXCEL_FILES/3_Mortality/WPP2012_MORT_F13_3_LIFE_EXPECTANCY_60_FEMALE.XLS.

VID 2014. European demographic data sheet 2014. Vienna, Austria: Vienna Institute of Demography. http://www.iiasa.ac.at/web/home/research/researchPrograms/WorldPopulation/PublicationsMediaCoverage/ModelsData/EU_data_sheet_2014.pdf.

Weber, Daniela, Vegard Skirbekk, Inga Freund and Agneta Herlitz 2014. The changing face of cognitive gender differences in Europe. *Proceedings of the National Academy of Sciences* 111(32): 11673–78. doi:10.1073/pnas.1319538111.

Yang, Zhou, Edward C. Norton and Sally C. Stearns 2003. Longevity and health care expenditures the real reasons older people spend more. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 58(1): S2–10. doi:10.1093/geronb/58.1.S2.

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Towards a reconceptualising of population ageing in emerging markets

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Abstract

Variously defined, the ‘emerging markets’ [EMs] are frequently held up as the countries that will shape global economic development in the 21st century. However, it is also often said that population ageing could limit growth in many EMs. In this paper, we explore the conventional measurements employed to demonstrate population ageing in EMs, and then move on to discuss whether these measurements are, indeed, ‘fit for purpose’ when studying EMs. Drawing on the literature on ‘prospective ageing’ (pioneered by Sanderson and Scherbov), we present an alternative set of ageing measurements based on a boundary for ‘dependency’ drawn from remaining life expectancy rather than chronological age. Using these measurements, population ageing – at least as defined here – can be seen as a much more manageable prospect for many EMs. We also examine the challenges and the opportunities for EMs associated with population ageing, and consider their potential advantages relative to the EU and North America in managing this trend.

1 Background

1.1 What are ‘emerging markets’?

As is implied by the name, ‘emerging markets’ [EMs] are generally defined as countries in a transitional phase towards developing a full market economy based on

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industrial modes of production and greater economic freedom. However, the term 'emerging markets', which was first coined by Antoine van Agtmael in 1981, is by no means uncontroversial. While it was initially seen as a more dynamic alternative to the expression 'third world' and to the politically incorrect term 'less-developed countries', the 'emerging markets' label has been questioned in terms of both its composition and its meaning. Organisations like Standard & Poors, the FTSE, the IMF, and Dow Jones have used different criteria in defining what constitutes an emerging market.

One definition of an emerging market, provided by Vladimir Kvint (2008; 2009), is as follows:

> *An Emerging Market is a society transitioning from a dictatorship to a free-market-oriented-economy, with increasing economic freedom, gradual integration with the Global Marketplace and with other members of the GEM (Global Emerging Market), an expanding middle class, improving standards of living, social stability and tolerance, as well as an increase in cooperation with multilateral institutions.*

Alternative groupings of countries and acronyms for these categories have recently gained currency, including the term 'BRICS', an acronym for Brazil, Russia, India, and China (and, in some cases, South Africa). BRICS, which was first coined in 2001 by Goldman Sachs chief economist Jim O'Neill, is thus used to refer to four (or five) large countries that are expected to play increasingly critical roles in shaping the global economy. More recently, the BRICS countries have been joined by the 'MINT' countries: namely, Mexico, Indonesia, Nigeria, and Turkey. Finally, the London Stock Exchange divides the 'emerging markets' category of countries into 'advanced emerging', 'secondary emerging', and 'frontier' markets.

In this paper, we use a special subset of 21 EMs for analysis, grouped into four quasi-regions.[1] Clearly, there are many question marks over the inclusion of some countries and the exclusion of others. However, we believe that the creation of this subset represents a reasonable attempt at assembling a group of countries that are broadly expected to play very significant roles in shaping the global economy in the 21st century.

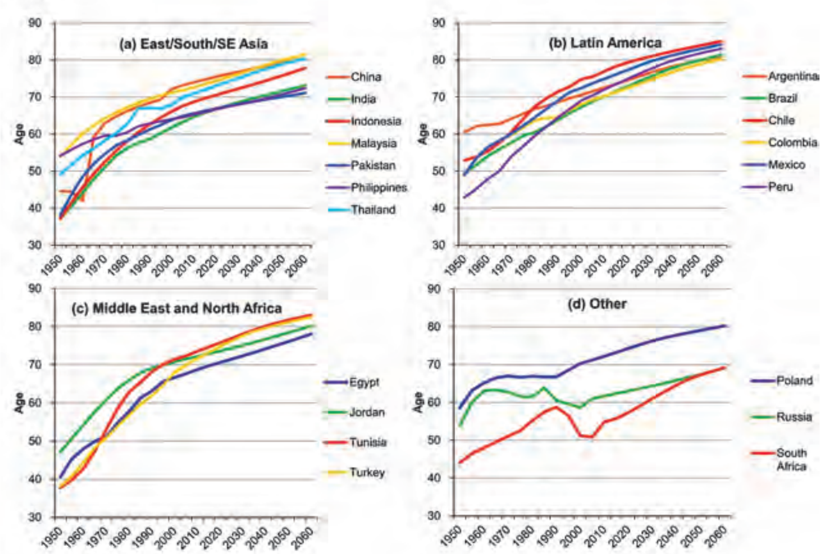
1.2 Population ageing in emerging markets: The orthodox view

In addition to undergoing dramatic economic and political changes, EMs have experienced equally seismic demographic changes over the past 50 years. As Figure 1 shows, across the EMs there have been marked increases in life expectancy

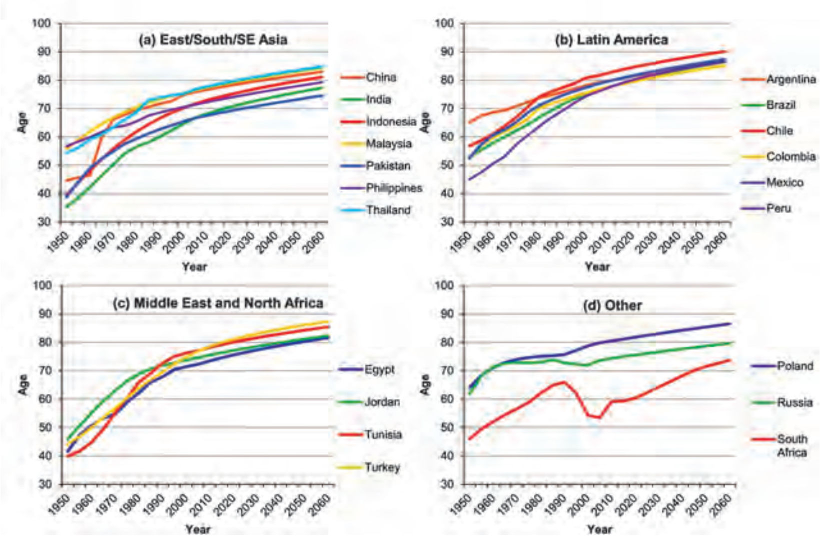
[1] China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand (East, South-East, and South Asia); Argentina, Brazil, Chile, Colombia, Mexico and Peru (Latin America); Egypt, Jordan, Tunisia and Turkey (Middle East and North Africa); Poland, Russia, and South Africa (other).

Figure 1:
Recent trends and forecasts of life expectancy at birth in four groups of EM countries. [a] Latin America; [b] E/SE/S Asia; [c] MENA; [d] Others

Males

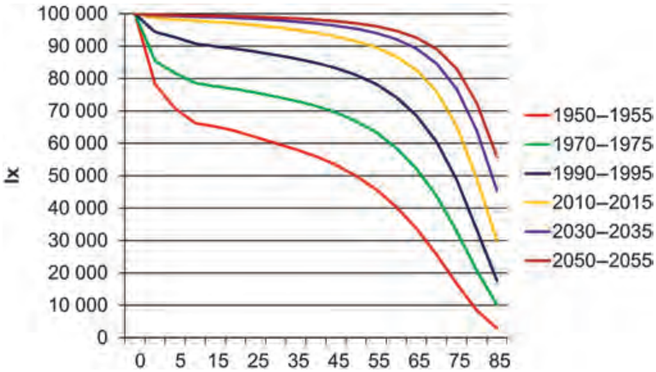


Females



Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Source: UNPD 2013

Figure 2:
Survivorship *(lx)* curve, Turkey, 1950–2060

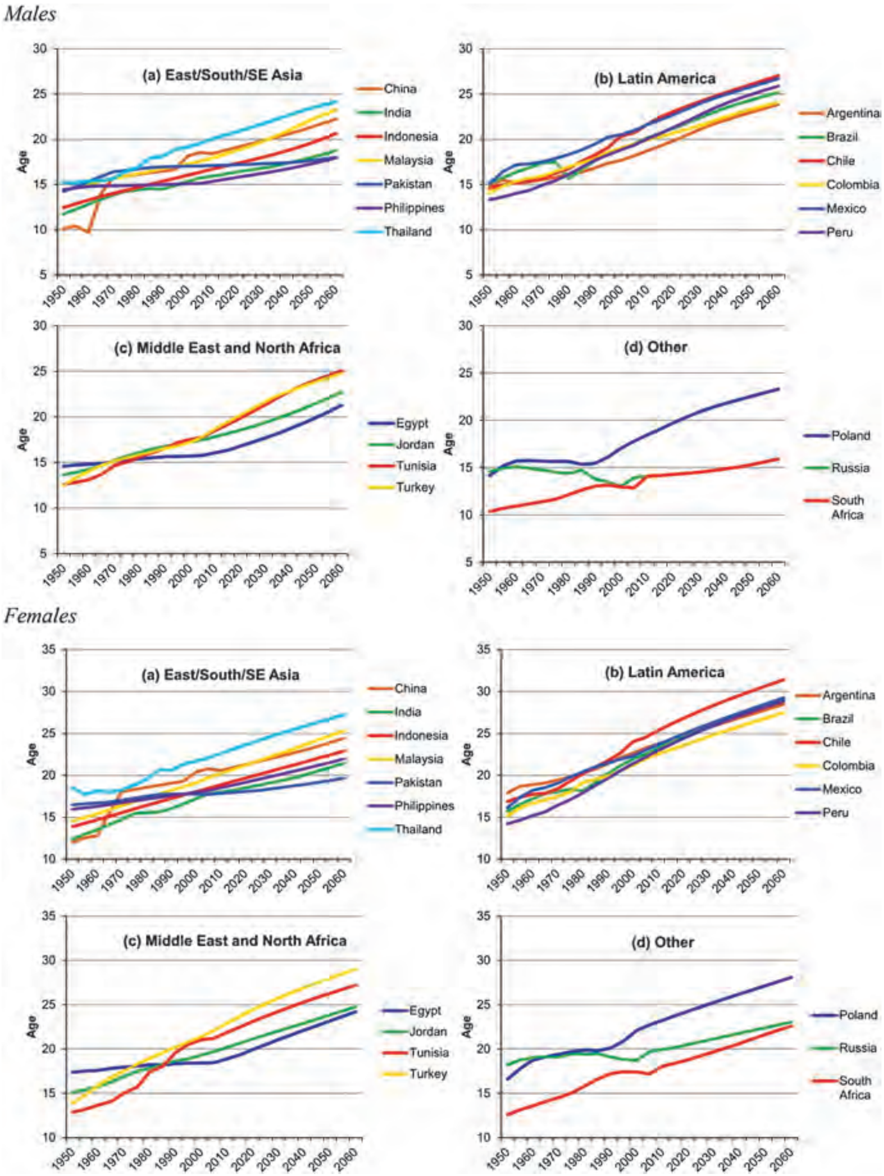


Source: UNPD 2013.

at birth for both males and females – albeit with some important outliers, such as South Africa and Russia, where previous mortality improvements have been thrown into reverse over the past two decades. Large shares of these overall improvements in life expectancy have been driven by reductions in mortality rates among infants and children (see Caselli et al. 2014 and Garbero and Pamuk 2014 for a review) and an increasing rectangularisation of the survival curve. Looking at Figure 2, we can see this pattern for Turkey: while the country saw dramatic improvements in early-age mortality during the mid-20th century, lower mortality at older ages has driven the overall mortality improvements in Turkey in recent years, and is projected to continue to do so in the future. Despite this caveat, as Figure 3 shows, there have been equally large improvements in life expectancy at age 60 for both males and females (again, with the same notable outliers). Thus, it is inaccurate to simply say that mortality improvements among older people have led to a trend towards 'ageing from above' in EMs. Rather, the recent improvements in mortality and health over the entire life course have led to increased survivorship rates; and, hence, to rising numbers of people surviving to older ages. Most of the scholarly literature, including a recent survey of population experts (see, for example, Caselli et al. 2014 and Garbero and Pamuk 2014) has forecasted that these mortality improvements will continue into the medium term.

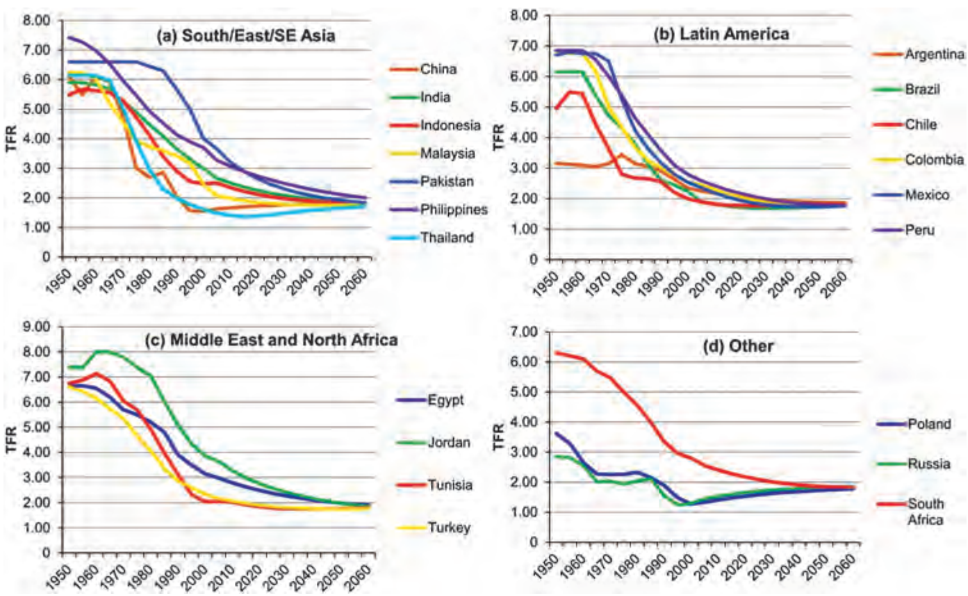
It has also been argued that EM populations have 'aged from below' as a consequence of rapid declines in fertility. The often dramatic decreases in fertility can be seen in Figure 4. In 1950, all of the EMs in our dataset with the exception of Poland, Russia, and Argentina had total fertility rates [TFRs] above five, with all but three having TFRs above six. Today, only Pakistan, the Philippines, and Jordan have TFRs above three. Meanwhile, Thailand, China, Tunisia, Poland, Russia, Malaysia, Chile, and Brazil, all have TFRs below the replacement level; with China having

Figure 3:
Recent trends and forecasts of life expectancy at age 60 in four groups of EM countries. [a] Latin America; [b] E/SE/S Asia; [c] MENA; [d] Others



Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Source: UNPD 2013.

Figure 4:
Recent trends and forecasts of total fertility rates [TFR] in four groups of EM countries. [a] Latin America; [b] E/SE/S Asia; [c] MENA; [d] Others

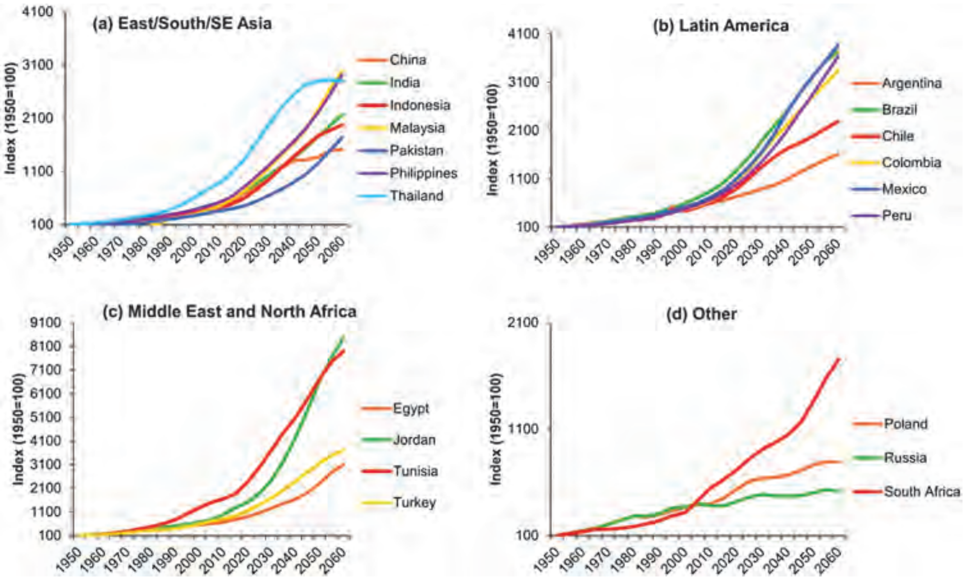


Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Medium fertility variant used.
Source: UNPD 2013.

one of the lowest fertility rates in the world. In India, 10 states currently have TFRs below two (for an overview of these recent trends, see Basten et al. 2014 and Goujon and Fuchs 2014). While the scale of the decline in fertility across the country set is very large, the *pace* at which this decrease has occurred – especially when compared to the trends in European countries, where the fertility decline began over a century ago – is breathtaking. It is therefore clear that the process of 'ageing from below' as a consequence of fertility decline has contributed substantially to the overall ageing of the populations in EMs.

Future patterns of fertility are, however, more uncertain. In Figure 4, we employed the medium variant of the UN's *World Population Prospects: 2012 Revision*. Yet in the literature and in a recent survey of experts, some scepticism about this indicator have been expressed. While space does not permit a full review of this debate here, it is important to note that the UN's assumptions regarding fertility are not universally accepted. The main points of contention are concerning the future paths of countries (such as China and Thailand) that are currently

Figure 5:
Recent trends and forecasts of the total population size aged 65+ in four groups of EM countries. [a] Latin America; [b] E/SE/S Asia; [c] MENA; [d] Others

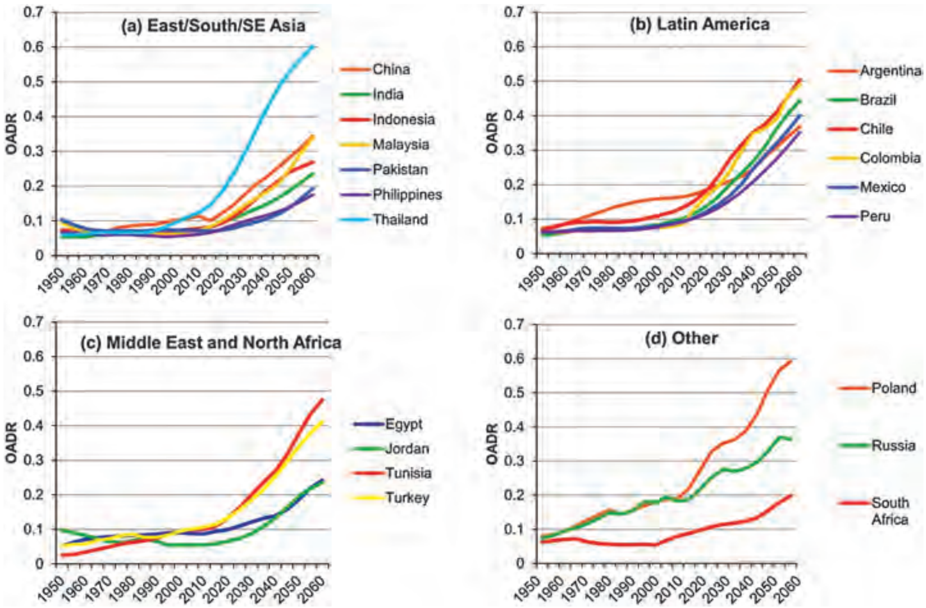


Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Medium fertility variant used.
Source: UNPD 2013.

characterised by very low fertility (see Basten et al. 2014 and Goujon and Fuchs 2014 for a review).

So how do these trends affect population ageing? First, we might consider the ‘absolute’ increases in the older population. Using the standard measurements employed by the UN and most scholarly and policy documents, Figure 5 shows the absolute increase in the total population aged 65 or older based upon an index of 100 in 1950. It would be fair to say that the increases are dramatic in all countries, although some are certainly more dramatic than others. For example, in Jordan and in Turkey the shares of the population aged 65+ are projected to increase more than 90-fold relative to the shares in 1950. Meanwhile, in Latin America and in Asia, increases of 20-fold and 30-fold are anticipated. What is crucial to note, however, is that the bulk of these increases are expected to occur in the next few decades; causing the increases that occurred in the 20th century to appear relatively modest by comparison.

Figure 6:
Recent trends and forecasts of the old-age dependency ratio (population aged 65+/population aged 20–64) in four groups of EM countries. [a] Latin America; [b] E/SE/S Asia; [c] MENA; [d] Others



Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Medium fertility variant used.
Source: UNPD 2013.

However, in thinking about the management of population ageing, it is arguably more useful to consider the size of the older population *relative* to the sizes other age groups – and especially to the size of the population of ‘working ages’. In making such comparisons, the old-age dependency ratio [*OADR*] is the ‘go-to’ measurement that is almost universally employed in scholarly, policy, and popular discourses on ageing. The sheer ubiquity of the *OADR* in the scholarly and the policy literature does not need to be demonstrated here. In the OADR, the population aged 65 or older counts as the numerator, while the population aged between a given lower bound (assumed to be 20 here) and 64 is the denominator. The people aged 65+ are deemed to be ‘old’ and ‘dependent’ upon those aged 20–64, who might be considered to be a sort of *de facto* labour force. The *OADRs* for the EM countries are displayed in Figure 6. The numbers represent the number of ‘old people’ who are ‘dependent’ upon each person aged (in this case) 20–64.

Looking at these *OADRs*, it is not difficult to see why population ageing is considered to be such a significant issue, or is even characterised as a *threat*: in the EMs, the OADRs are on track to increase sharply over the coming decades. Currently, the *OADRs* are below 0.17 for all of the EMs in our set except Argentina, Chile, Poland, and Russia. In other words, each person aged 20–64 is currently ‘supporting’ no more than 0.17 people aged 65+ in these countries. Meanwhile, the ratio is much higher in some non-EM countries: the OADR is 0.39 in Japan; and is between 0.30 and 0.35 in Germany, Italy, Sweden, and Greece. Among the EMs, the highest current *OADRs* are 0.24 in Poland, 0.20 in Russia, and 0.20 in Argentina. Although Chile and Thailand have *OADRs* of 0.17 and 0.16, respectively; South Africa, Egypt, Colombia, Peru, Mexico, Tunisia, Turkey, Brazil and China have *OADRs* of between 0.10 and 0.15 (in ascending order). Jordan, the Philippines, Pakistan, Indonesia, Malaysia, and India have current *OADRs* of between 0.07 and below 0.1 (again, in ascending order).

But by mid-century, these ratios look very different. In the Latin American EMs, there is a near uniform increase to between 0.39 (Peru) and 0.56 (Chile), with most of the OADRs clustered between 0.4 and 0.5. In E/SE/S Asia, China, and Thailand, the OADRs are projected to increase extremely rapidly and intensely, to between 0.54 and 0.65. Indeed, by 2050 the population of Thailand will be as ‘old’ as the populations of Germany and Singapore. Elsewhere in this region, the OADR is projected to rise to 0.37 in Malaysia and to between 0.20 and 0.29 in the remaining countries. Among the MENA EMs, the OADR is set to jump to 0.53 in Tunisia and to 0.45 in Turkey. Increases of 150% are projected for Egypt and Jordan. In the ‘other’ group, the OADR is expected to further increase to 0.40 in Russia and to 0.62 in Poland, and to double in South Africa.

Yet before we discuss the ‘challenges’ associated with population ageing, as indicated by the *OADR*; we would be well advised to pause and think a little more carefully about what this widely used measurement is actually telling us. Indeed, a growing body of literature has developed in recent years suggesting that the *OADR* might not be such a useful measurement when examining population ageing in industrialised/OECD countries. The reasons why this might be the case have been extensively reviewed elsewhere (see, for example, Scherbov et al. 2014; Sanderson and Scherbov 2013; and Spijker and MacInnes 2014), and will be only very briefly summarised here. There are two main criticisms of the reliance on the OADR. The first criticism concerns change over time: i.e., when the boundary of ‘old age’ and ‘dependency’ is fixed at age 65 over the complete forecast period, changes in life expectancy (and, by implication, health) are not taken into account. The second criticism is rather more fundamental, and challenges the very idea of what it means to be ‘old’ and ‘dependent’, regardless of which threshold age is chosen. The literature that has made this criticism has drawn on themes such as the separation of the pensionable age and the retirement age (which rarely occurs at 65); differences in health care expenditures among people aged 65 and older; the need to consider differences in pension systems (and their increasing privatisation); and issues related to ‘active ageing’, including a questioning of the notion of ‘dependency’.

Elsewhere, Basten (2013) has argued that these criticisms are even more pertinent when considering non-European settings. For example, in Asian countries with very low levels of pension coverage and of state-provided support for older people – problems that are exacerbated by the large informal labour markets in many of these countries – the challenges relating to 'dependency' that the OADR implies are not adequately reflected. Again, even in countries that have pension systems, workers may be eligible to receive benefits before reaching age 65. Moreover, the existing systems differ in their levels of susceptibility to population ageing. For example, provident fund pension systems tend to be less vulnerable than pay-as-you-go systems.

While the EM country set is certainly heterogeneous in character, we suggest that there is a strong argument for reassessing the use of the *OADR* as the default/sole measurement of population ageing. In doing so, we must think carefully about what concerns us about population ageing, and about what precisely we mean by dependency. In the OECD context, we might think of dependency in terms of a tax-paying, formalised labour force transferring assets to an inactive, 'retired' population via the pension system and/or the medical/social care system.

First, we must consider the role of pensions. Again, this is not the place for an exhaustive review of the pension systems in the EM country set under analysis here (see Clements et al. 2014, and for reviews, see ssa.gov 2013a for Asia; ssa.gov 2013b for Latin America; ssa.gov 2014a for Africa and ssa.gov 2014b for Europe); not least because of the fast-changing, heterogeneous nature of these systems both between and *within* such countries, and given the complex web of conditions and eligibility criteria. Generally, however, we can state that pension provision in EMs is characterised by much lower replacement rates, lower levels of coverage, lower contribution levels, and stricter eligibility criteria than in EU states (although important exceptions exist, particularly in Latin America and Poland – see ssa.gov 2014a and 2014b; OECD 2013). Thus, in most of these countries, public pension expenditures represent a relatively small percentage of GDP (e.g., 0.7% in Pakistan and Indonesia compared to an OECD average of 8.4%). Furthermore, the pension systems that exist tend to differ from the PAYG systems of many European countries. For example, countries such as Malaysia and Indonesia have provident fund-type systems that rely less on intergenerational transfers, and are instead based primarily on fund/stock market performance. Thus, these systems are arguably less susceptible to population ageing. Finally, with the exception of most of the Latin American countries and Poland, the retirement age is significantly lower in the EMs than in the majority of European states, which suggests that there is a degree of leeway for future reform – a point we shall return to later. Indeed, if we were to take the age of pension eligibility as the boundary of old age and dependency, as implied by the European/historical context (see Sanderson and Scherbov 2013 and Basten et al. 2013 for a review); then a recalculated *OADR* would be significantly higher, and the sense that an 'ageing crisis' is occurring would be further exacerbated.

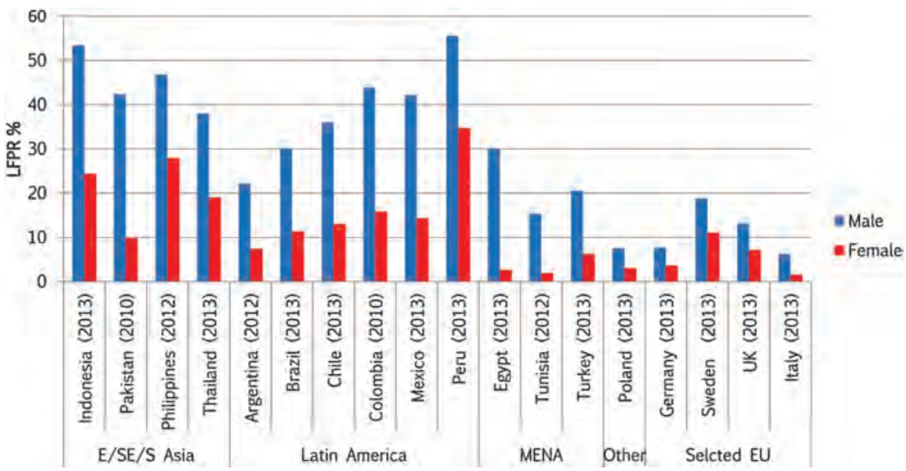
The second major concern raised in the literature relating to the 'problem' of population ageing is the potential growth in health care expenditures. Again, a comprehensive review of EM health care systems is not possible here (see, for example, WEF 2014), but some general points regarding the quality, the accessibility, and the funding of health care can be broadly made. In the WHO's 2010 ranking of world health systems, only Colombia ranks in the top 25, with Chile and Argentina ranking 33rd and 34th, respectively; although it should be noted that the per capita public expenditures on health in these Latin American EMs are relatively high. Even in EMs with nascent (or established) universal health care systems, the systems of long-term social care for the elderly tend to be weak (e.g., Deloitte 2014). Crucially, however, in both OECD and EM countries, health care expenditures are much more strongly correlated with proximity to death rather than with reaching a particular age (see Gray 2005 for a review). In other words, the number of people aged 65 and older only becomes truly relevant in terms of projected health care expenditures when considered in relation to the overarching mortality patterns (see Spijker and MacInnes 2014 for an example from the UK).

In making these two observations about the state of pension and health care provision in EMs, it important to note that we recognise that an unfair comparison is being made with Europe and with various other OECD countries. However, this is precisely the point. Much of the current framing of the 'ageing crisis' – and, indeed, the tendency to measure it using the *OADR* – is viewed through the lens of large-scale, formalised, post-industrial economies with very high levels of human capital, and in which very large transfers have historically taken place at around age 65. These conditions are very different in EMs, yet we often conceptualise ageing in these countries as occurring in similar ways.

A final point that relates to the notion of being 'dependent' after turning 65 refers to the literature on 'productive ageing'. In many OECD countries, this discourse is largely based around a narrative of 'active ageing', and of the contributions made by 'older'/retired people to civil society through voluntary activities, or to their families through child care arrangements (see, for example, Avramov and Maskova 2003). These notions have been mentioned in the literature on EM countries as well (see various chapters in Morrow-Howell and Mui 2012, especially Du and Yang 2012 for China). Yet another feature of active engagement in later life should also be highlighted: namely, labour force participation [LFP] among people aged 65+. As Figure 7 shows, LFP among this age group is generally much higher in EMs than in other European/industrialised economies. For males, the LFP rates are above 50% in Indonesia and Peru; above 40% in Colombia, Mexico, Pakistan, and the Philippines, and above 20% in Argentina, Brazil, Egypt, and Turkey. Female LFP rates are significantly lower, primarily because women have less access than men to employment.

While the active ageing agenda in OECD countries has largely been seen as a 'positive' challenge to activate older human and social capital, these higher LFP rates in EMs are not necessarily a positive sign. Indeed, as is frequently the case in many EM labour markets as a whole, large percentages of the elderly workforce are engaged in poorly paid labour in the informal sector, either as casual workers or as self-employed individuals in low skilled or unskilled occupations. As Amireddy

Figure 7:
Labour force participation among 65–69-year-olds, selected EMs, various surveys, 2010–2013



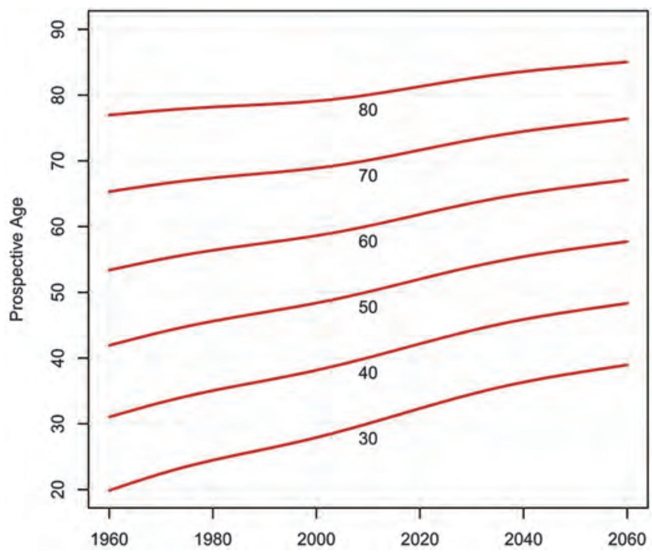
Source: ILOSTAT 2014.

(2013) noted, 'this suggests that given the inadequate social security for the majority of the older persons and the declining traditional support from adult children with the growth of nuclear families, continuing to work can be the only option for old age support for the majority in India'. However, it is not our place here to make a normative judgement as to the nature of elderly labour force engagement in EMs. Instead, our aim is merely to demonstrate that it is common for people in these countries to continue to work after age 65, and that the problem of 'dependency' among people aged 65+ might therefore be less acute than expected.

1.3 An alternative approach: Thinking prospectively?

Figure 8 provides an alternative approach to thinking about the relationship between increases in life expectancy and different time elements across the life course. Crucially, it helps to picture the difference between chronological age and prospective age. *Chronological* age refers to the number of years a person has lived, while *prospective* age refers to the number of years a person is expected to live. As Ryder (1975, p. 16) remarked: 'To the extent that our concern with age is what it signifies about the degree of deterioration and dependence, it would seem sensible to consider the measurement of age not in terms of years elapsed since birth but rather in terms of the number of years remaining until death'. This approach guides our exercise here. Looking at the graph, we can see that at the centre is the index (set at 2010) of both chronological and prospective age. Keeping remaining life

Figure 8:
Trajectories of constant prospective ages (α-ages) over time, Turkey, males (standard 2010)



Source: authors calculations based on UNPD 2013.

expectancy [*RLE*] constant, we can see why a 60-year-old – in this example, a man in Turkey – with a *RLE* of 60 in 2010 would be equivalent to a 67-year-old in 2060, and to a 53-year-old in 1960. In other words, when we compare the life expectancies of men in Turkey over this 50-year period, the expression '40 is the new 30' seems to apply. But for the older population under analysis here, we could say that '70 is the new 65'; and that by 2050, '65 is the new 60'. Aside from life expectancy, it is highly likely that the health status of these three 'older men' are going to be entirely different when their age is measured chronologically. This concept has been elucidated at length elsewhere by Sanderson and Scherbov and others. For an extended discussion of prospective age, please see, for example, Scherbov et al. (2014), Sanderson and Scherbov (2013, 2007 and 2005), Basten (2013), and Spijker and Macinnes (2014).

Sanderson and Scherbov have developed a number of new methods for measuring age that take these changes in life expectancy into account. In estimating the 'prospective old age dependency ratio' [*POADR*], a fixed *RLE* must first be established. The *RLE* is set at the point at which a person is defined as 'old' or 'dependent'. This point then changes as total life expectancy increases (or decreases) (see Figures 1 and 3).

Various studies (e.g., Basten et al. 2013) have tried to identify a suitable *RLE* reflecting the boundary at which the final period of dependency begins. However, as suggested above, before we can define the RLE, we must first engage in a fundamental reappraisal of what we mean by ‘old’ and ‘dependent’; and, indeed, determine much more precisely what it is we want to measure. In the literature, there is a general consensus that the *RLE* should be 10–15 years. Sanderson and Scherbov (2010) have suggested basing this boundary on an *RLE* of 15 years [hereafter RLE_{15}], as this was the remaining life expectancy of 65-year-olds in many low mortality countries in the 1960s and the 1970s. This figure can then be compared with earlier conceptualisations of what it means to be ‘dependent’. More importantly, however, based on international evidence of health and social care expenditures (see, for example, Zweifel et al. 1999 and Gray 2005), we can assume that ill health, morbidity, and the need for long-term care are most likely to fall within this period of life. Thus, RLE is defined as a period of ‘physical dependency’ during which people are likely to need expensive forms of care.

In the remainder of this paper, we will first calculate the age at which *RLE* equals 15, and present this as an alternative ‘boundary’ for the construction of ‘dependency’. Using this new boundary, we will then proceed to calculate a new series of dependency ratios. These ‘prospective’ old-age dependency ratios could be seen as alternatives to the traditional old-age dependency ratio.

2 Data and methods

For this exercise, we utilise the input data from the UN’s *World population prospects: 2012 revision*, including the UN life tables (l_x) that are graduated to single years of age and time. We use single year population totals based upon the medium fertility variant of the UN’s projections. For a critique of these assumptions, see the discussion section below.

To recap, we compare the *POADR* and the *OADR* with the formulas below:

$$OADR = \frac{\textit{number of people aged } 65 \textit{ and over}}{\textit{number of people aged } 15\text{–}64}$$

$$POADR = \frac{\textit{number of people} \geq \textit{age at RLE} = 15}{\textit{number of people aged} \geq 20 \textit{ and} \leq \textit{age at RLE} = 15}$$

The results will be presented for each EM country grouped into four quasi-regions. The limitations of a universal application of this dataset to all countries under analysis here are addressed in the discussion section below.

3 Results

3.1 RLE_{15} as a new boundary of 'dependency' in EMs

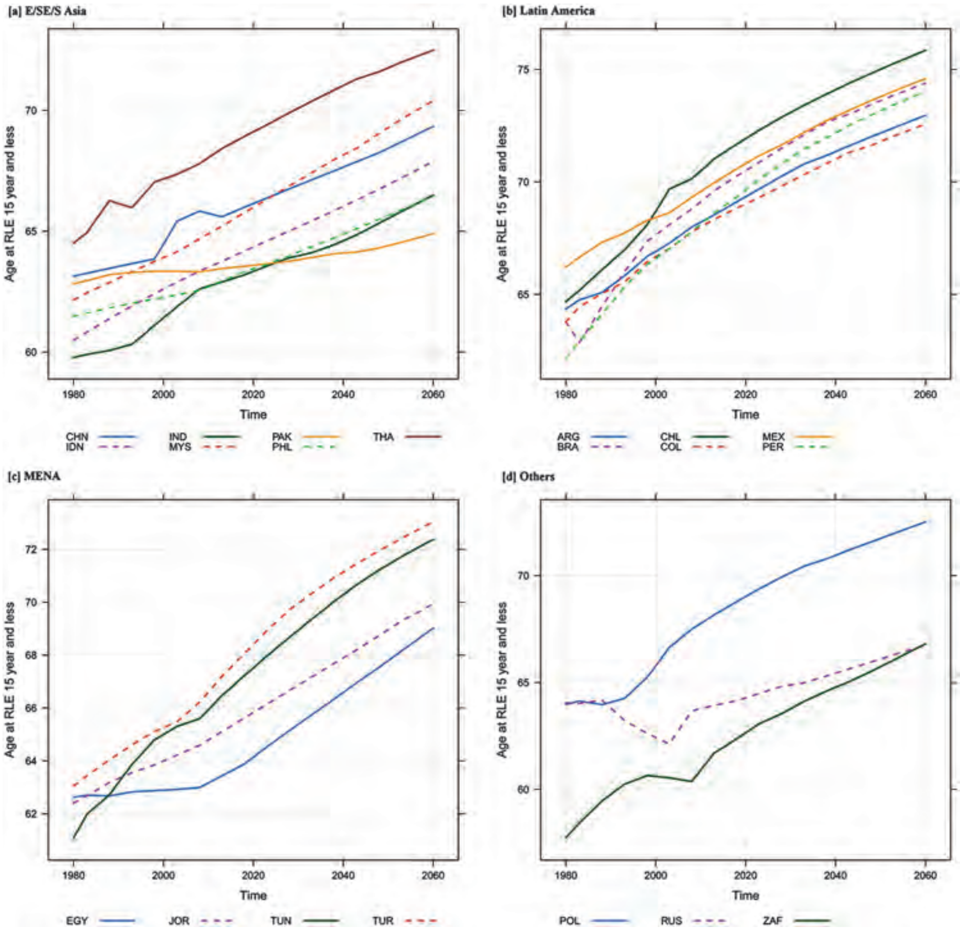
As Figures 9a–d demonstrate, the ages at which the RLE_{15} begins clearly differ significantly both temporally and spatially, and are largely determined by the recent histories of mortality patterns in the respective EMs. We can immediately see that the dramatic recent (and projected) improvements in mortality are radically altering the age at which the RLE_{15} begins. Returning to the prospective ages presented for Turkey in Figure 8, we can see that Turkey is far from being an isolated example. When we look at the Latin American EMs, we can comfortably argue that in Chile, for example, '70 is the new 65', and that by the end of the forecast period, '76 will be the new 70'. Such scenarios can be presented throughout the dataset. If, for example, we compare in Tunisia life expectancies 30 years in the past with life expectancies 30 years in the future, we can say that '70 is the new 60'.

Thus, it is clear that there is little justification for using 65 as a pivotal 'boundary year' after which a person enters a period of 'old age' and 'dependency', based on the construction of dependency outlined above. For some countries, the age at which the RLE_{15} begins has been well above age 65 for two or even three decades. In the E/SE/S Asian EMs, the age at which the *RLE* at age 65 became greater than 15 years was reached in Thailand in the early 1980s, in China in the early 2000s, and in Malaysia very recently (Figure 9a). In the Latin American EMs, for example, all of the countries had passed this point by the early 1990s (Figure 9b). When we look at the remaining EMs, we see that this threshold was broken in the past 15 years in Jordan, Tunisia, Turkey, and Poland (Figures 9c–d). This indicates that for these countries, *the 'boundary' of 'dependency' was set too low in the past*, based on this particular construction of dependency. The natural corollary of assumption is that for the period until the age at which RLE_{15} starts exceeded 65, the 'boundary' of 'dependency' had been set too low for these countries.

But what about the countries for which the RLE_{15} still starts below age 65? For example, in the E/SE/S Asian EMs, the age at which the RLE_{15} starts is not projected to rise above 65 until the mid-2020s in Indonesia, the early 2040s in India and in the Philippines, and the early 2060s in Pakistan. Elsewhere, the age at which the RLE_{15} starts is forecast to rise above 65 in Egypt in the late 2020s, in Russia in the mid-2030s, and in South Africa in the early 2040s. Thus, the implication here is that based on this particular construction of dependency, *the 'boundary' of 'dependency' is set too high in our forecasts* until this point is reached.

In sum, if we consider RLE_{15} as an alternative 'boundary' of 'dependency' based upon a set of assumptions about the concentration of ill health and other care needs, it becomes clear that the persistent use of the chronological age of 65 as a boundary does not reflect the dynamic nature of shifting patterns of mortality and life expectancy.

Figure 9:
The age at which *RLE₁₅* begins in four groups of EM countries. [a] E/SE/S Asia; [b] Latin America; [c] MENA; [d] Others

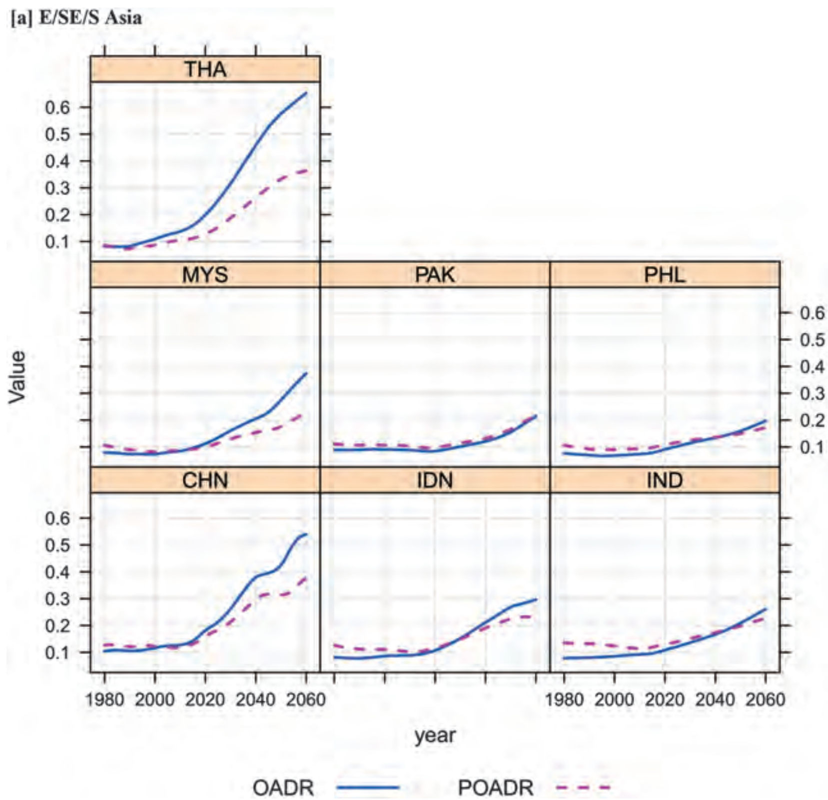


Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Source: authors calculations based on UNPD 2013.

3.2 Prospective old-age dependency ratios for EMs

As we noted above, Sanderson and Scherbov have developed an alternative set of measurements that translate the shifting patterns of RLE_{15} as a 'boundary' of 'dependency' into a ratio. As we explained above, the prospective old-age

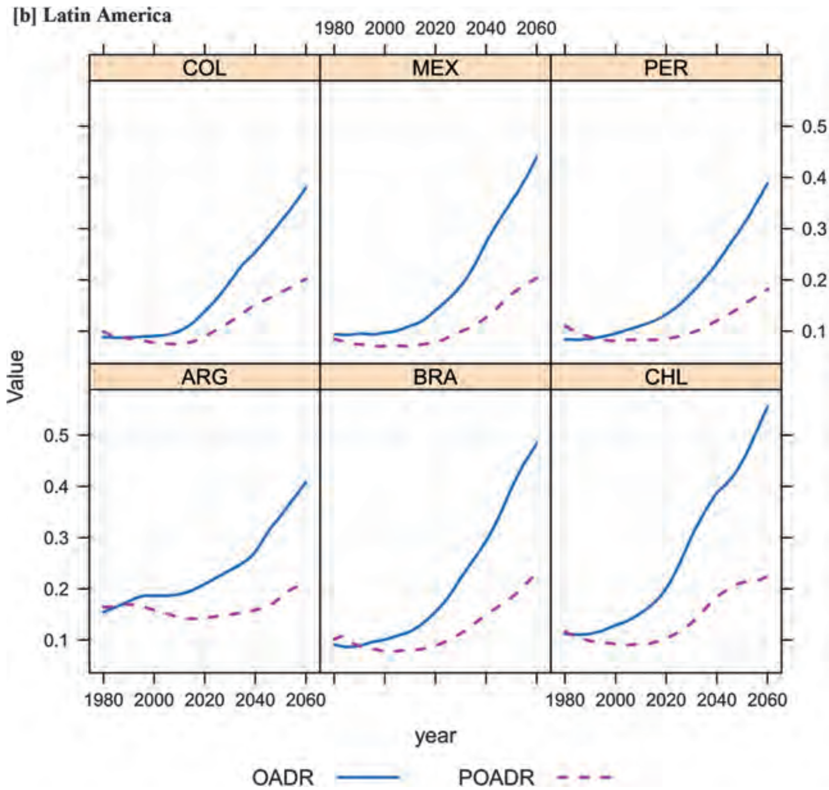
Figure 10a:
Comparing *OADR* with *POADR* in four groups of EM countries. [a] E/SE/S Asia; [b] Latin America; [c] MENA; [d] Others



dependency ratio [*POADR*] takes the denominator as a fixed lower bounded age (here, 20 chronological years of age) through to a dynamically changing upper bound effectively set at the point at which the *RLE* is 16 years. The numerator is taken to be the entire population aged at or above the age in the life table at which the *RLE* is (or is forecast to be) 15 years. Figures 10a–d compare the 'standard' *OADR* with the *POADR* calculated for each EM country. (Note that the complete schedules of *OADR* and *POADR* for all EMs are reproduced in Appendix A. Furthermore, for purposes of comparison, an abridged dataset of *POADR*s for other countries can be downloaded from this website).

Each of the Latin American EMs is characterised by significant gaps between the *OADRs* and the recalculated *POADR*s, largely due to the relatively low fertility rates coupled with strong improvements in mortality patterns in these countries. By the end of the forecast period, the *OADRs* in Argentina, Colombia, Mexico, and Peru

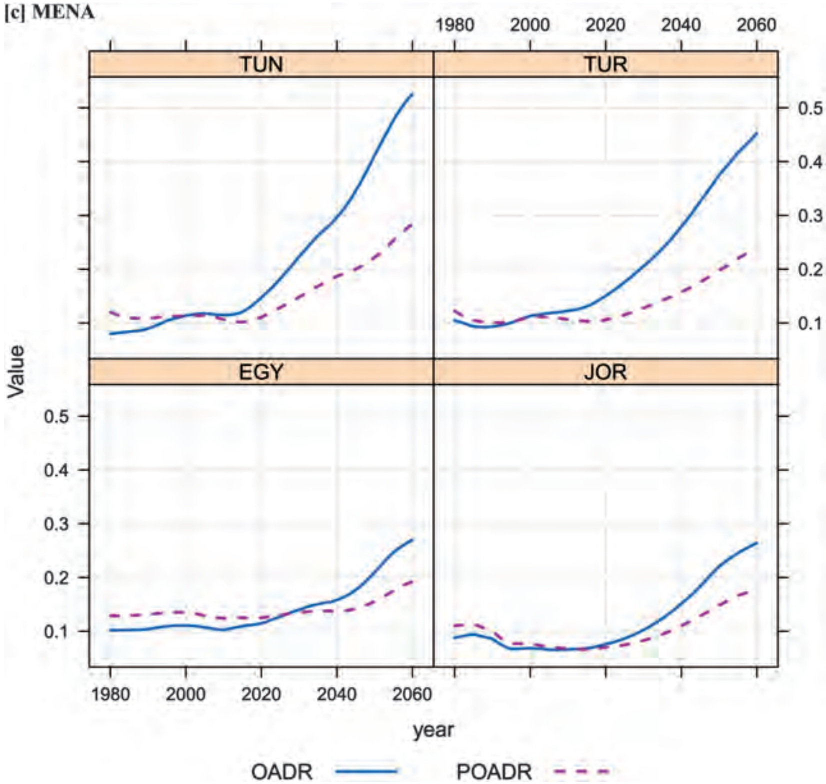
Figure 10b:



are around twice as high as the *POADRs*, with this multiple rising to around 2.5 in Brazil and to almost 3.0 in Chile.

In E/SE/S Asia, the picture is more mixed. In Thailand, there is a large difference between the forecast *OADR* and the *POADR* owing to this country's very low fertility rate and improvements in mortality. More modest differences can be found in Indonesia, Malaysia, and China. However, given China's population size and economic power, even a relatively modest difference in the 'dependency ratio' could have important ramifications not just for China itself, but for the region as a whole. The differences between the *OADR* and the *POADR* are much smaller in the other EMs in the region, even at the end of the forecast period. In Pakistan and the Philippines, the pace of population ageing is relatively slow due to persistently high fertility rates, and the differences between the ratios are also small. A final point regarding national heterogeneity should be made here. In all of the countries in this region – indeed, in all of the EMs – there are important regional differences in fertility and mortality levels and in migration patterns; and, hence, in degrees of population ageing. It is important to keep this regional heterogeneity in mind when

Figure 10c:

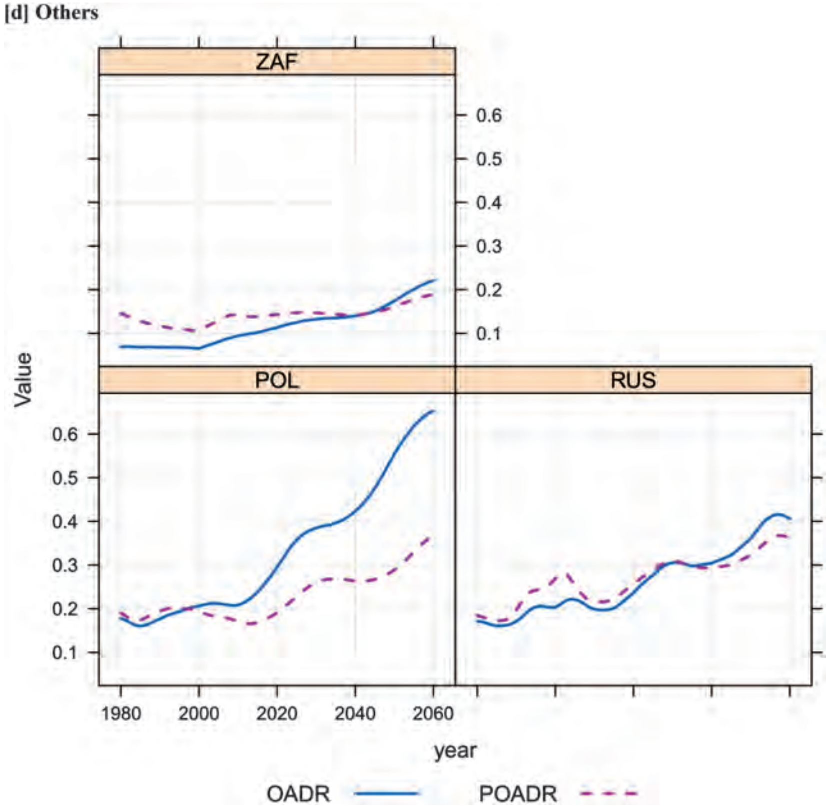


considering the world's two population 'billionaires': China and India. Given their sheer size and the power exercised by their provincial-level governments, we can expect to observe substantial regional variation within China and India.

The MENA EMs also represent something of a 'mixed bag.' In both Tunisia and Turkey, there are very large differences between the *POADRs* and the *OADRs* by mid-century, with the prospective-based ratio being roughly half as large as the *OADRs*. Again, these gaps are largely attributable to the relatively low fertility rates and strong improvements in mortality in these counties. In Jordan and Egypt, by contrast, higher fertility rates and worse mortality conditions result in lower overall *OADR*s; and thus in smaller, but still notable, gaps between the *OADR*s and the *POADR*s.

Finally, in the category of 'other EMs', we again see large differences. Low fertility and mortality improvements in Poland lead to rapid ageing under the *OADR* measurement: i.e., to a ratio of 0.65 by 2050. However, under a scenario using prospective calculations, this increase is much more modest, from around 0.18 today to 0.35 by mid-century. Russia's very poor mortality track record contributes to the

Figure 10d:



Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia, and ZAF = South Africa (Other).
Source: authors calculations based on UNPD 2013.

relatively modest differences between the *OADR* and the *POADR* in that country. Finally, in South Africa, relatively high fertility and relatively poor mortality conditions lead to lower overall rates of ageing.

A final point can be made that links back to the previous discussion on setting the *RLE* at 15 years. For a large number of the analysed countries, the *POADR* had been *higher* than the *OADR* in the recent past. Indeed, in some countries (Egypt, Indonesia, India, Pakistan, South Africa, and Russia), the *POADR* is *still* higher than the *OADR* today; albeit usually by very modest amounts. This implies that based on our construction of dependency, ageing may have been 'undermeasured' in the past when the *OADR* alone was used.

4 Discussion

There are, of course, a large number of limitations to our exercise. The first concerns the 'independent' population, or the denominator. For consistency, we set the lower bound at 20 years of chronological age across the entire country set. It, is, however, clear that this cut-off point is much more appropriate for some countries rather than for others. Compare, for example, Pakistan and Brazil, where the 2010 labour force participation rates of males aged 15–19 were higher than 50%; with Russia and Poland, where the same rates were lower than 10% (ILOSTAT 2014). The second concern relating to the calculation of the denominator is that the 'nature' of these denominators could differ across the EMs, as this denominator is weakly defined not only in our calculations, but also in the *OADR*. In assuming that the total number of people between age 20 and > RLE_{15} represent a *de facto* labour force, we do not take into account the very different characteristics of these 'working-aged' populations across this rather heterogeneous group of EMs. For example, countries differ in the degree to which their labour market is formalised, and in their levels of labour force participation, particularly among women. Moreover, it is clear that the structural issues surrounding pensions and old-age care liabilities are not the same across countries. As we noted in the background section above, we need to account for differences across countries not only in the types of pensions that are prevalent, but in current levels of liability for pension and care provision.

A second point of criticism lies in the definition and use of RLE_{15} as a boundary for 'dependency'. First, there is clearly an issue relating to the creation of binary 'dependent' and 'independent' populations. Just as proponents of the OADR are foolish to assume that people become 'old' and 'dependent' upon reaching their 65th birthday, proponents of the POADR could very well be open to the same charge for assuming that people become dependent upon reaching the age at which RLE equals 15 years. Second, setting the RLE at 15 years is arbitrary, and is based on relatively little solid empirical evidence. Third, by applying this boundary across the entire population, differences in health and mortality (by, for example, gender, occupation, and class) are ignored. The importance of this problem is emphasised in Sanderson and Scherbov 2014, which utilises survey data to measure the speed of ageing across population subgroups in the US. Fourth, the use of RLE_{15} over the entire projection period does not allow for further delays in the onset of morbidity and ill health, and thus for a potential decrease in the number of years spent in so-called 'dependency'.

The final criticism revolves around the assumptions employed in the exercise. Again, for consistency, we have used the latest UN *World Population Prospects* for all countries. Assumptions regarding future improvements in mortality are taken for granted here, even though these improvements may not occur. However, the scholarly consensus regarding the fertility assumptions employed by the UN – especially in settings characterised by very low fertility – is much less solid (see, for example, Basten et al. 2014).

While all of these limitations are significant, it is also important to note that we do not intend to present these alternative measurements of population ageing as some kind of panacea. In the first section of the paper, we demonstrated why the conventional means of measuring population ageing using the old-age dependency ratio is increasingly obsolete in Europe and North America, and – arguably, even more so – in many EMs.

In the current paper, we have attempted to present just one of the alternative approaches that could be used to study (and measure) population ageing and 'dependency' in EMs. This alternative measurement is just another tool that can be added to the demographer's toolkit, and that can be recommended to policy-makers and other stakeholders in EMs. If this measurement approach empowers policy-makers to take a more 'rational' view of population ageing – i.e., a perspective that takes into account improvements in health and longevity, and that guides them away from a worst-case scenario of a seemingly unavoidable future characterised by intense and rapid population ageing, as the *OADR* projections tend to show – and thus to avoid 'policy paralysis', then it will prove useful.

Finally, the real contribution of these alternative measurements is that they might lead policy-makers and other stakeholders in EMs to think much more carefully and deeply about what the precise challenges of an ageing population actually are. Only by designing and executing improved measurements can demographers identify where the future stresses might lie in different scenarios of population ageing. Since the EM economies are, by their very nature, 'emerging', the future implications of an ageing population are likely to be very different in these countries than in the OECD or the EU countries. Arguably, the EMs still have substantial opportunities for harnessing the demographic dividend. For example, they could formalise the labour market (which would increase contributions to existing pension systems and help in the development of future social welfare programs); they could further develop their human capital and their technological assets (to increase productivity); and they could encourage the provision of services through the private sector. In sum, if we compare the EMs with the countries of Europe, we can see that the current nature of ageing and of 'dependency' (and the boundaries of 'old age' and 'dependency') differ considerably between them, but so does the outlook for the future.

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References

Amireddy, B. 2013. Labour force participation of elderly in India. Paper presented at International Union for the Scientific Study of Population conference, Busan, Republic of Korea, September 2013. URL: http://iussp.org/sites/default/files/event_call_for_papers/Extended_abstract.PDF.

Avramov, D. and M. Maskova 2003. *Active ageing in Europe*: Vol. 1. Brussels: Council of Europe Publishing.

Basten, S. 2013. Redefining "Old Age" and "Dependency" in East Asia: Is "Prospective Aging" a more helpful concept? *Asian Social Work and Policy Review* 7(3): 242–248.

Basten, S., P. Yip and E. Chui 2013. Remeasuring ageing in Hong Kong; or 'keeping the demographic window open'. *Journal of Population Research* 30: 249–64.

Basten, S., T. Sobotka and K. Zeman 2014. Future fertility in low fertility countries. In Lutz, W., Butz, W. and KC, S. (eds). *World population & human capital in the twenty-first century.* Oxford: Oxford University Press: pp. 39–146.

Caselli, G., S. Drefahl, C. Wegner-Siegmundt and M. Luy 2014. 'Future mortality in low mortality countries.' In Lutz, W., Butz, W. and KC, S. (eds). *World population & human capital in the twenty-first century*. Oxford: Oxford University Press: pp. 226–272.

Clements, B. et al 2012. The challenge of public pension reform in advanced and emerging market economies. International Monetary Fund, Washington DC. Occasional Paper. No. 275.

Deloitte 2014. *2014 Global health care outlook: Shared challenges; shared opportunities*. London: Deloitte.

Du, P. and H. Yang 2012. China's population ageing and active ageing. In Morrow-Howell, N. and Mui, A. C. (eds). (2012). *Productive engagement in later life: A global perspective*. Abingdon: Routledge pp. 33–46.

Goujon, A. and R. Fuchs 2014. Future fertility in high fertility countries. In Lutz, W., Butz, W. and KC, S. (eds). *World population & human capital in the twenty-first century.* Oxford: Oxford University Press: pp. 147–225.

Garbero, A. and E. Pamuk 2014. Future mortality in high mortality countries. In Lutz, W., Butz, W. and KC, S. (eds). *World population & human capital in the twenty-first century.* Oxford: Oxford University Press: pp. 273–332.

Gray, A. 2005. Population ageing and health care expenditure. *Ageing Horizons* 2: 15–20

ILO 2014. *ILOSTAT database*. Geneva: International Labour Organisation.

Kvint, V. 2008. Define emerging markets now. *Forbes.com*. URL: http://www.forbes.com/2008/01/28/kvint-developing-countries-oped-cx_kv_0129kvint.html. Date accessed January 9th 2015.

Kvint, V. 2009. *The global emerging market: Strategic management and economics*. New York, London: Routledge.

Morrow-Howell, N. and A. C. Mui (eds) 2012. *Productive engagement in later life: A global perspective*. Abingdon: Routledge.

OECD 2013. *Pensions at a glance 2013: OECD and G20 indicators*. Paris: OECD.

Ryder, N. B. 1975. Notes on stationary populations. *Population Index* 41: 3–28.

Sanderson, W. C. and S. Scherbov 2014. Measuring the speed of aging across population subgroups. *PLOSone* 9(5): e96289.

Sanderson, W. C. and S. Scherbov 2013. The characteristics approach to the measurement of population aging. *Population and Development Review* 39: 673–685.

Sanderson, W. C. and S. Scherbov 2007. A new perspective on population ageing. *Demographic Research* 16(2): 27–58.

Sanderson, W. C. and S. Scherbov 2005. Average remaining lifetimes can increase as human populations age. *Nature* 435: 811–813.

Scherbov, S., W. C. Sanderson, S. KC and W. Lutz 2014. Re-measuring twenty-first century population ageing. In Lutz, W., Butz, W. and KC, S. (eds). *World Population & Human Capital in the Twenty-First Century.* Oxford: Oxford University Press: pp. 563–590.

Spijker, J. and J. MacInnes 2014. Population ageing: the timebomb that isn't? *BMJ* 347: f6598.

ssa.gov 2013a. *Social security programs throughout the world: Asia and the Pacific, 2012*. Washington DC: Social Security Administration.

ssa.gov 2013b. *Social security programs throughout the world: Africa, 2013*. Washington DC: Social Security Administration.

ssa.gov 2014a. *Social security programs throughout the world: The Americas, 2013*. Washington DC: Social Security Administration.

ssa.gov 2014b. *Social Security programs throughout the world: Europe, 2014*. Washington DC: Social Security Administration.

UNPD 2013. *World population prospects: The 2012 revision*. New York: United Nations Population Division.

WEF 2014. Health systems leapfrogging in emerging economies. World Economic Forum, Project Paper. January 2014.

Zweifel, P., S. Felder and M. Meiers 1999. Ageing of population and health care expenditure: a red herring? *Health Economics* 8: 485–496.

Appendix: *OADR* and *POADR* for EMs, a subset of countries

Country	Measure	1980	1990	2000	2010	2013	2020	2030	2040	2050
ARG	POADR	0.165	0.169	0.159	0.145	0.143	0.142	0.150	0.159	0.184
BRA	POADR	0.102	0.088	0.079	0.081	0.081	0.089	0.113	0.149	0.183
CHL	POADR	0.116	0.098	0.092	0.091	0.093	0.104	0.134	0.184	0.213
CHN	POADR	0.127	0.122	0.122	0.119	0.126	0.160	0.213	0.297	0.314
COL	POADR	0.099	0.086	0.078	0.075	0.077	0.089	0.118	0.152	0.176
EGY	POADR	0.129	0.131	0.135	0.124	0.126	0.125	0.135	0.137	0.156
IDN	POADR	0.126	0.112	0.111	0.102	0.103	0.115	0.149	0.191	0.225
IND	POADR	0.135	0.133	0.123	0.114	0.116	0.130	0.151	0.173	0.198
JOR	POADR	0.110	0.101	0.076	0.068	0.067	0.070	0.083	0.110	0.148
MEX	POADR	0.085	0.074	0.071	0.071	0.073	0.078	0.099	0.127	0.172
MYS	POADR	0.105	0.089	0.082	0.085	0.089	0.101	0.129	0.153	0.175
PAK	POADR	0.110	0.106	0.106	0.102	0.099	0.097	0.114	0.132	0.166
PER	POADR	0.110	0.088	0.081	0.083	0.083	0.085	0.097	0.120	0.150
PHL	POADR	0.106	0.092	0.090	0.092	0.094	0.108	0.124	0.136	0.149
POL	POADR	0.190	0.194	0.192	0.171	0.165	0.191	0.261	0.263	0.289
RUS	POADR	0.184	0.196	0.268	0.217	0.217	0.255	0.308	0.293	0.322
THA	POADR	0.086	0.073	0.087	0.105	0.108	0.127	0.187	0.264	0.332
TUN	POADR	0.120	0.109	0.114	0.106	0.102	0.111	0.148	0.187	0.222
TUR	POADR	0.122	0.101	0.110	0.107	0.104	0.106	0.128	0.158	0.198
ZAF	POADR	0.146	0.117	0.107	0.142	0.138	0.143	0.147	0.142	0.161
ARG	OADR	0.155	0.175	0.186	0.190	0.193	0.209	0.237	0.273	0.343
BRA	OADR	0.091	0.089	0.101	0.117	0.126	0.155	0.221	0.294	0.396
CHL	OADR	0.113	0.112	0.129	0.153	0.164	0.201	0.302	0.388	0.449
CHN	OADR	0.105	0.106	0.116	0.127	0.133	0.181	0.262	0.380	0.425
COL	OADR	0.088	0.088	0.090	0.100	0.108	0.138	0.197	0.254	0.314
EGY	OADR	0.102	0.104	0.111	0.103	0.107	0.115	0.140	0.158	0.210
IDN	OADR	0.081	0.078	0.086	0.089	0.091	0.107	0.152	0.212	0.269
IND	OADR	0.078	0.080	0.085	0.092	0.094	0.108	0.136	0.166	0.208
JOR	OADR	0.088	0.086	0.068	0.066	0.067	0.076	0.103	0.151	0.221
MEX	OADR	0.094	0.095	0.097	0.110	0.115	0.141	0.189	0.273	0.353
MYS	OADR	0.079	0.073	0.073	0.084	0.091	0.112	0.160	0.205	0.275
PAK	OADR	0.088	0.089	0.090	0.088	0.086	0.084	0.101	0.120	0.155
PER	OADR	0.084	0.085	0.095	0.111	0.116	0.133	0.174	0.233	0.304
PHL	OADR	0.076	0.069	0.068	0.073	0.075	0.091	0.114	0.134	0.159
POL	OADR	0.178	0.176	0.206	0.208	0.222	0.295	0.385	0.423	0.554
RUS	OADR	0.171	0.171	0.203	0.199	0.197	0.236	0.305	0.304	0.360
THA	OADR	0.082	0.083	0.109	0.137	0.148	0.199	0.316	0.458	0.575
TUN	OADR	0.080	0.090	0.114	0.115	0.116	0.147	0.223	0.297	0.412
TUR	OADR	0.105	0.093	0.113	0.123	0.126	0.151	0.205	0.279	0.374
ZAF	OADR	0.069	0.068	0.065	0.094	0.099	0.113	0.132	0.139	0.174

Note: CHN = China, IND = India, IDN = Indonesia, MYS = Malaysia, PAK = Pakistan, PHL = Philippines, THA = Thailand (East/SE/South Asia); ARG = Argentina, BRA = Brazil, CHL = Chile, COL = Colombia, MEX = Mexico, PER = Peru (Latin America); EGY = Egypt, JOR = Jordan, TUN = Tunisia, TUR = Turkey (Middle East and North Africa); POL = Poland, RUS = Russia and ZAF = South Africa (Other); POADR = prospective old age dependency ratio, OADR = old-age dependency ratio.
Source: authors calculations based on UNPD 2013.

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Population ageing dynamics in the North Atlantic region of the Arctic

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Abstract

This paper contributes to our understanding of the demographic developments and the transition to older age structures in the sparsely populated Arctic region: in Iceland and in the two Danish autonomous territories of the Faroe Islands and Greenland. We compare the population ageing dynamics of the region with those of mainland Denmark for the 1980–2015 period. We also examine whether population ageing has been developing differently in the communities of the North than in Denmark, and shed light on the question of whether a regionally specific policy approach to population ageing is required. In our study, ageing is measured by applying a dual methodology. The two sets of indicators are based on calculations of "chronological" and "prospective" ages. The latter is an innovative approach developed by Sanderson and Scherbov (2008) that considers improvements in life expectancy over time. Our results show that the size of the North Atlantic region's older population is well below the Danish national average. According to chronological indicators, the ageing rates have been rising in recent years. Prospective indicators, which take into account changes in population longevity, also provide information about competing trends in population rejuvenation. In addition, the prospective approach reveals a cross-territorial convergence in recent decades, as well as a slower pace of ageing that can be accounted for in policy planning.

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1 Introduction

1.1 Study aims

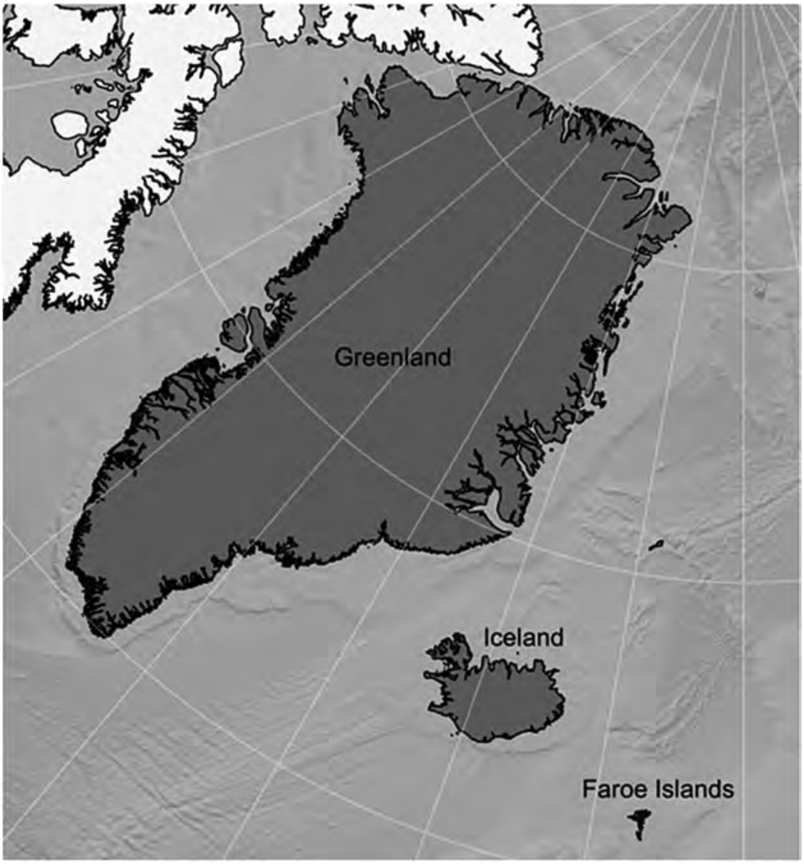
The dynamics of “getting older” are central to “every single aspect of planning at every single imaginable level: from the individual to the workplace to the societal to the global levels” (Leeson 2002, 5). Indeed, the phenomenon of population ageing, which is currently taking place almost everywhere in the world, is unfolding on a scale hitherto unseen in human history. The question of how societies should deal with population ageing has sparked heated debates across political and scientific forums, especially in countries where life expectancy is very high, and the population has reached its highest-ever point in terms of maturity (World Health Organization 2011). At the same time, in the existing research, ageing that occurs at a subnational and at smaller territorial levels has received considerably less attention than ageing in major world regions and across countries.

Past research has shown that the rate of population ageing observed within remote communities of the Arctic region differs, sometimes significantly, from the average rates of the countries to which those communities belong, and from the rates of the southern territories of Arctic countries. This pattern has been observed in various parts of the Arctic, such as in the Barents Euro-Arctic region (Danilova et al. 2011; Nummela et al. 2011; Emelyanova and Rautio 2012; Emelyanova and Rautio 2016), the Russian North (Danilova and Golubeva 2011; Emelyanova and Rautio 2013), the Nordic region (Nordregio publications, cited below), the North American Arctic (Moore and Pacey 2004; Hamilton and Mitiguy 2009; Wilson et al. 2012; Lewis 2013), and across the Arctic as a whole (Larsen and Fondahl 2014; Emelyanova 2015). These authors have generally found that the ageing process in the sparsely populated communities of the Arctic can transform those communities at every level, and can profoundly distort the age composition of local populations. Subnational-level data from these studies suggest that policy action on ageing that takes into account the particular characteristics of the North is needed, and that modifications of policy action at the national level may be required if cross-territorial differences are found to be substantial.

The North Atlantic region of the Arctic includes Iceland and two autonomous territories of Denmark: namely, the Faroe Islands and Greenland (Figure 1). These areas have many common features. For example, all of these areas have (i) a closed geographical location, (ii) a high degree of peripherality and isolation, (iii) geopolitical status as part of Europe, (iv) an egalitarian social structure, (v) a parliamentary system of government, (vi) a small domestic market with fishing being a predominant source of income, and (vii) a population living in either relatively small urban centres or remote settlements. There is something of a gap in the demographic literature on this part of the Arctic, especially with regard to the ageing of its population. We aim to fill this gap with this study.

Several papers published in English have contributed to our understanding of the demography of coastal societies of the North Atlantic (Foss and Juvkam 2005;

Figure 1:
The area of the study: North Atlantic, including Iceland, Greenland, and the Faroe Islands



Source: The North Atlantic Marine Mammal Commission, http://www.nammco.no/.

Gløersen 2005; Rauhut et al. 2008; Hansen et al. 2011; Rasmussen 2011; Hansen et al. 2012b; Hörnström and Roto 2013, Roto et al. 2014, Roto and Rasmussen 2016). However, relatively few of these papers have addressed the issue of societal ageing, even though population ageing, along with urbanisation, are among the most pronounced demographic trends of recent years.

According to the sources cited above, the demographics of the North Atlantic region have changed dramatically over the past 40 years. Migration has been a strong driver of this change, with many consequences for the age structures of small communities. Currently, as in the past, large-scale industrial projects and recurrent financial crises in the region are triggering waves of migration. For instance, the main demographic crisis in the Faroe Islands is related to changes in the fisheries sector. While the sector was successful in the 1970s, it experienced a collapse associated with overfishing in the 1990s, which in turn led to overinvestment, unemployment, and out-migration. As a result of heavy emigration between 1989 and 1994, the population of the Faroe Islands declined by 10%. Since the 2000s, positive economic changes have stabilised migration. In the case of Greenland, the island moved from Danish colonial status to Home Rule in 1979. This new status led to a large wave of out-migration, and the emigration rate of native Greenlanders did not decrease until more attractive workplaces were established and investments in education were made in the territory. Thousands of people emigrated from Iceland in 2008–2009 in the wake of the financial collapse of 2008; this was the largest wave of migration from Iceland since 1887.

These historical events have caused the populations of the North Atlantic region to age rapidly. Although the region still has higher birth rates than most European countries, emigration rates have been especially high among people of reproductive ages. The older population has risen most sharply in Iceland and in Greenland, where the age structures had been young, but changed due to significant outflows of people of childbearing age, and particularly of young women pursuing educational and career opportunities elsewhere. As these trends have distorted the birth-death balance, societal ageing has become particularly intense in remote coastal areas of the North Atlantic.

In light of these developments, the aim of this paper is to construct a comprehensive cross-regional profile of demographic ageing in the North Atlantic for the 1980–2015 period using the available background data. We identify the major demographic events that have been contributing to the shift towards the ageing of the North Atlantic populations. In addition to using the traditional approach to measuring ageing, we are rethinking ageing trends, and thus apply a new "prospective" methodology. This approach allows us (i) to identify the oldest and the youngest areas in the region, as well as the areas that are ageing the fastest and the slowest (or that are, by contrast, rejuvenating); (ii) to compare the ageing rates of the Danish autonomous territories to those of mainland Denmark; and, finally, (iii) to examine whether the ageing trends are converging or diverging across the countries and territories of the North Atlantic. The analysis will be of interest to demographers, social scientists, and policy planners. Appendix 1 summarises the ageing rates for the North Atlantic and Denmark for both sexes for the period under study.

1.2 Methods

In this study, we measure population ageing by applying a dual methodology, and compare the results of the traditional and the new "prospective" approaches to measuring ageing. The main difference between the two methodologies is the age on which these measures are based: the chronological age or the prospective age.

The traditional indicators of population ageing include the median age (MA), the share of people over the age of 60 (Prop 60+), the ageing index (AI), and the old-age dependency ratio (OADR) (e.g., monitored in United Nations 2015). The MA is represented by a line drawn to numerically divide the population into two equal parts: one older and one younger than the age at the dividing line. The Prop 60+ relates the population aged 60 and older to the total population. The AI refers to the percentage of people aged 60 and older divided by the number of children aged zero to 14. The OADR relates the number of people aged 60 and older to the number of people aged 15 to 59.

These indicators are based on chronological age; that is, on the number of years already lived. As these indicators are monitored internationally and are cited in most studies on societal ageing, they allow researchers to make broad regional and even global comparisons of ageing trends. The computation techniques used to construct these indicators are relatively simple, as they involve subdividing population statistics by age and sex. In this text, we refer to results related to these indices as having been measured in a "traditional" or a "chronological" way.

Traditional measures are based on a simplified understanding of ageing, with chronological age being the only parameter considered. However, a number of scholars have recently argued that these indicators are too limited (Denton and Spenser 2000; Sanderson and Scherbov 2008, 2010). According to these authors, the age of an individual is not commensurable across different historical points in time. For example, a Greenlander who was aged 60 in 1900 had far fewer remaining years of life than his 60-year-old descendant living today due differences in life expectancy (LE), health, and well-being during these two periods. These observations have led scholars to rethink how we measure age and ageing, with new metrics of ageing being introduced by Scherbov and Sanderson (2008). These new measures incorporate changes in people's characteristics beyond traditional chronological age, such as prospective age and changes in remaining life expectancy (RLE).

If we are considering purely chronological age, we know that a person who had reached the age of, say, 50 in 1900 or in 2015 had lived for precisely 50 years. If, however, we are considering prospective age, we cannot assume that the person's remaining number of years was constant between 1900 and 2015, given that today's LE at older ages is longer and is continually increasing. For a more detailed explanation of prospective age, we refer the reader to the publications of Sanderson and Scherbov (2008, 2013, 2016), who originated and developed the concept of prospective ageing.

Here we give one explanatory example linked to the North Atlantic context. In 1900, a 50-year-old Icelandic woman had 20.4 remaining years to live, while a 50-year-old Icelandic man had 17.4 remaining years to live (Table 1). We estimated new prospective ages in 1950, 2000, and 2015 based on these RLEs from 1900. Between 1900 and 2015, the prospective ages of 50-year-old Icelandic men and women rose by around 15 years. Thus, in Iceland in 2015, 66-year-old women and 67-year-old men were "the new 50-year-olds" relative to their forebears of 1900. This substantial

Table 1:
The calculated prospective ages in 1950, 2000, and 2015 at which remaining life expectancy (RLE) is the same as at the age of 50 in 1900, by sex, standard year – Iceland 1900

	Males	Females
RLE at the age of 50 in 1900	17.4	20.4
1950	60.3	59.8
2000	65.4	64.0
2015	67.4	66.1

Source: Data on life expectancies at different ages were obtained from the Human Mortality Database and Statistics Iceland (for the year 2015). Prospective ages are calculated by the authors.

growth in RLE cannot be ignored when population ageing is measured, as failing to take prospective age into account may give a false picture of how old the society in question was in the past, is in the present, and will be in the future.

The prospective indicators in this analysis include the share of people with an RLE of 15 years or less (Prop RLE 15), the prospective median age (PMA), the prospective ageing index (PAI), and the prospective old-age dependency ratio (POADR). The PMA is derived from the life table in which the remaining LE is the same as the MA in the reference year: in this study, the life table refers to Iceland in 2005. The Prop RLE 15 is calculated as the number of people in age groups in which the RLE is 15 years or less, divided by the total population. The POADR makes the share of people older than the RLE of 15 years or less the old-age threshold in the numerator, which is divided by the number of people between the ages of 15 and the old-age threshold. The PAI relates the number of people older than RLE 15 or less to the number of children between the ages of zero and 14. More information on the computation techniques used for prospective indicators can be found in the publications of Sanderson and Scherbov from 2008 to 2016 (see references).

Prospective indices consider changes in longevity, and refer to a floating number of prospective years to live, as denominated in Table 1, instead of a constant number of chronological years. For the chronological indices, a 60-year age threshold is used in the calculations. It may sound artificial to consider all people older than age 60 as old. This population group is highly heterogeneous and is largely still productive in labour market terms. Moreover, retirement ages can be well above 60; in Iceland, for example, the official retirement age is 67 (Hansen et al. 2012, 18). However, this analysis focuses on demographics rather than on labour force analysis, and 60 is chosen as a reasonable basis for cross-regional comparisons. As the age threshold of 60 is used in a pan-Arctic study on ageing (data available in Emelyanova [2015]), relying on this threshold also facilitates numerical comparisons on ageing between the North Atlantic and the rest of the Arctic region. Regardless of whether we use an age threshold of 60 or 65, the trends in ageing dynamics measured will show the same pattern.

2 Results and discussion

The North Atlantic region has a population that is already out of balance in many respects (Rauhut et al. 2008; Hansen et al. 2011, 2012a, 2012b; Roto et al. 2014). The complex interrelations of migration, natality, death rates, and family choices suggest that the size and the characteristics of this population are changing dramatically, and that policy regulation is needed. Without entering into a broader discussion of these issues, it is important that we mention several intraregional demographic features of the area under study: (i) North Atlantic reproduction rates are comparatively high, but have been declining in recent decades due to changes in mortality and fertility; and (ii) migration heavily distorts the birth-death balance, and leads to particularly intense societal ageing trends in rural and remote areas. These areas are ageing rapidly because large shares of young people (notably young women) leave to find employment, marry, and further their education in the capitals and larger cities of the North Atlantic, including Nuuk, Reykjavik, Akureyri, and Tórshavn. Below, we identify the scope of ageing heterogeneity and cross-territorial trends for recent decades in the North Atlantic setting.

2.1 Patterns of longevity at a later age

Longevity is a powerful driver of population ageing. Greenland's average LE was lower than that of Iceland and the Faroe Islands at the beginning of the 1980s, which caused a noticeable cross-territorial gap. In 2015, the populations of Iceland and the Faroe Islands had a life expectancy of 82 years, or eight years more than the population of Greenland (Statistics Iceland 2016; Statistics Faroe Islands 2016; Statistics Greenland 2016). In fact, Icelandic men have a LE at birth (81 years) that is among the highest in the world, and that is two years higher than the LE of Faroese men. The life expectancies of Icelandic females and males have been steadily converging due to male "leapfrogging" (Statistics Iceland 2016).

Alternative measures of ageing use the expected time to death derived from life tables. Lutz and colleagues have argued that the traditional LE at older ages should be complemented with estimates of how many people with an RLE of 15 years or less there are in the population, as these people are more likely to be dependent on public services than the population aged 60 or 65+ (Lutz et al. 2008). While life expectancy has increased across the region, it has grown to varying degrees at different ages (Table 2). Longevity has clearly risen more slowly at later ages than at birth. For example, an average increase of 5–8 years in LE at birth translates into an average increase of just 1–4 years at the ages at which RLE is equal to 15 (Age RLE 15). In recent decades, the growth in the age at which RLE 15 is reached has been insignificant among Greenlandic men and women, but has been particularly strong in the Faroe Islands due to recent increases in longevity, and possibly due to improvements in the national health care system.

Another indicator that directly reflects changes in longevity is the median age (MA). If we compare the MA standardised for expected RLE (prospective) with traditional (retrospective) LE, we see that the MA provides more accurate estimates of changes in the length of a population's life and health. The MA in the North Atlantic has been gradually rising for both sexes, and has increased by almost 10 years over the past three decades. In 2013, the MA of the region's population reached 36 years, or four years lower than the Danish MA. In 1980, by contrast, the MA of the North Atlantic population was eight years lower than the Danish MA. While the cross-territorial differences have diminished, the gender gap in the MA has been consistent throughout the period, with women having an MA that was 2–3 years higher than that of men in all territories.

The median age has increased due to two trends that have intensified since the end of the 1960s: decreasing birth rates and increasing LE. While the birth rates in the North Atlantic have declined slightly less than in the Nordic region, and considerably less than elsewhere in Europe, these decreases have still been pronounced. Whereas the TFR (total fertility rate) in Iceland rose as high as four in 1964, it had fallen to 1.8 by 2015 (Statistics Iceland 2016). In Greenland, the TFR decreased from 2.7 in 1970 to 2.0 in 2015 (Statistics Greenland 2016). In the Faroe Islands, the TFR declined from 3.4 to 2.4 over the same period (Statistics Faroe Islands 2016). Deviations from the levels of fertility attained will also have large effects on population change. According to United Nations forecasts, Iceland and the Faroe Islands will have TFRs of 1.8 in 2050; while according to the authors' projections, the TFR in Greenland will grow to 2.2 by 2050.

Future birth rates could also be affected by national policies, and, to some extent, by abortion rights. In Greenland, women have full access to abortion services; while in the Faroe Islands and Iceland, access to abortion is restricted to certain cases of medical or social necessity. The abortion rate in Greenland grew substantially over several decades prior to the 2000s, whereas in the other two territories, where abortions are restricted, the rates have been low (Johnston 2016). However, there have been no drastic changes in abortion rates in the recent past, possibly because more information is being made available about contraception and family planning. The question of why these policies have affected fertility rates at the local level needs to be further investigated. It has been suggested that the North Atlantic is entering the final stage of the Demographic Transition model (from high to low births and deaths). Additional changes in fertility at the local level could be caused by higher educational attainment, financial uncertainties and crises in local economies, intense urbanisation, the labour market behaviour of higher educated women, and other local factors.

Conventional median ages have been compared to PMAs, which are calculated on the basis of period life tables and adjusted to the respective changes in life expectancy. Just as economic analysts compute the outputs of various countries

Table 2:
Longevity indicators in Denmark and the North Atlantic region by sex (male/female), 1980/2012

	Denmark		Greenland		The Faroe Islands		Iceland	
	1980	**2012**	**1977–1981**	**2008–2012**	**1985–1986**	**2011–2012**	**1980**	**2012**
Life expectancy at birth	71.4/77.4	78.0/81.9	60.3/67.7	68.7/73.4	72.1/79.4	79.6/84.6	73.5/79.5	80.8/83.9
Life expectancy at age 60	17.1/21.6	21.6/24.2	15.6/17.9	16.4/18.6	18.3/21.9	22.5/ 24.9	19.3/23.0	23.4/25.4
Age RLE 15	63.1/68.6	67.9/71.1	61.0/64.6	61.9/64.7	64.5/68.7	69.2/72.1	65.8/ 70.4	69.0/72.4
Median age	33.0/35.3	39.9/41.7	24.7/22.5	35.1/32.0	28.4/28.3	37.6/39.3	26.3/27.3	34.7/35.9
Prospective median age	43.5/36.9	45.1/39.5	37.1/33.5	42.8/40.5	34.5/33.0	36.9/38.7	31.9/30.9	33.9/34.5

Note: “Age RLE 15” is the age at which RLE (remaining life expectancy) equals 15 years. Age RLE 15 data are calculated for a one- to five-year (Greenland) average. All median age data are provided for the cut-offs at 1980 and 2012.

Source: Data on life expectancy at birth, at age 60, and at the median age (except for Denmark) are provided by Statistics Denmark, Statistics Greenland, Statistics Faroe Islands, and Statistics Iceland.

using a standard currency, demographers calculate the PMAs of various territories using a common life table as a reference (see Sanderson and Scherbov 2008). In our study, we matched the MA to one standard life table: that is, the life table that refers to Iceland in 2005. We identified the ages at which the RLE was the same as at the MA in the indicated year for the same territory. Appendix 1 contains the resulting calculations for the PMAs. A different picture of ageing emerged when we applied this technique: while the PMA was growing, it was increasing at half the pace of the MA: over three decades, the PMA rose 3–4 years (males–females), while a commonly used MA increased 8–9 years. Across the region, the PMA grew most rapidly in Greenland, where it increased 6.4 years in the 1980–2010 period. Over the same period, the PMA grew only 2.5 years in the Faroe Islands and in Iceland.

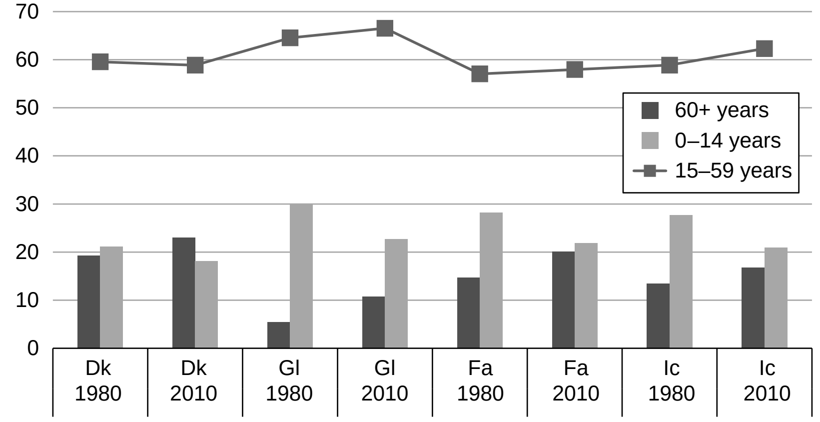
2.2 Age structure

In the North Atlantic, cohort effects as well as socioeconomic particularities continue to have a substantial impact on the development of the population age structure. One concern is that an ageing population may lead to increased demand for public services. Small island communities of the North Atlantic face many challenges related to ageing. For instance, because they have difficulties recruiting qualified specialists in gerontology, geriatrics, and other medical specialties, patients are sometimes sent for treatment to Denmark or Iceland. In addition to being expensive, this system can impose hardships on older people. Thus, further developments in local infrastructure and regional cooperation in the provision of medical care for the elderly are needed.

According to Gløersen et al. (2005: 64), demographic changes are “the most comprehensive synthetic indicator of economic and social dynamism”, and have a big impact on age structure. The North Atlantic experienced strong population growth in the last century. At the beginning of the 20th century, approximately 100,000 people lived in the Faroe Islands, Greenland, and Iceland. Within one hundred years, the population of Greenland had increased more than fivefold, the population of Iceland had increased fourfold, and the population of the Faroe Islands had more than tripled. These growth rates are tremendous when compared with the general population declines that were occurring in Europe and in other regions of the Arctic. However, from the 1990s onwards, this growth trend reversed, and turned into a trend towards “thinning out societies” (Aasbrenn 1989).

Currently, the populations of the North Atlantic region have the lowest proportions of elderly people and the highest shares of children and young people in the Nordic country group. While Greenland has the youngest population by any measure (Foss and Juvkam 2005), its birth rates have been declining in the period studied. In Iceland, the share of young people in the population has also increased. Thus, compared with the rest of the Europe, the region has a relatively young labour force.

Figure 2:
Danish and North Atlantic proportions of the population with a remaining life expectancy of 15 years or less (Prop RLE15-), sexes combined, (%) of total population, 1980–2010



Note: Dk: Denmark, Gl: Greenland, Fa: the Faroe Islands, Ic: Iceland. The data are the authors' calculations based on population counts and mortality numbers provided by Statistics Denmark, Statistics Greenland, Statistics Faroe Islands, and Statistics Iceland.

When the changes in broader population age groups (youth, adults, and the elderly) are tracked, clear shifts can be seen over the last three decades (Figure 2). The shrinking number of children and teenagers is a direct result of the tendency among young people in the North Atlantic to have fewer children. Urbanisation plays a large role in this shift. As Hansen et al. (2012) observed, the more rural areas of the Faroe Islands are experiencing a greater reduction in the proportion of the young people in the population than the rural areas of Greenland. Greenland has experienced a similar decline in its capital region, whereas in Iceland, there has been a decrease in all parts of the country.

Because of the relative lack of educational and employment opportunities in the North Atlantic, migration is a significant accelerator of population ageing in the region, causing the shares of young and working-aged people in the population to shrink. Although the North Atlantic is remote and travel is expensive, the people are mobile (Hansen et al. 2011), in part because Nordic citizens are permitted to move freely within the Nordic region under regional labour and educational policies (Dustmann and Albrecht 2011). There is, however, a noticeable gender discrepancy in the numbers of young people emigrating from small settlements, as women are more likely than men to permanently leave their home island communities and the region itself (Rasmussen 2005), taking with them their labour skills and potential offspring. More women than men from Greenland, and to a lesser degree from the Faroe Islands, have moved to Denmark to enter into interethnic marriages with

Danes. Some older people from Greenland and the Faroe Islands move to Denmark after retirement, which tends to increase the share of people aged 60+ in the Danish population. Figure 2 shows that Denmark had the largest share of people aged 60+ in the population in 1980 (19%) and in 2010 (23%).

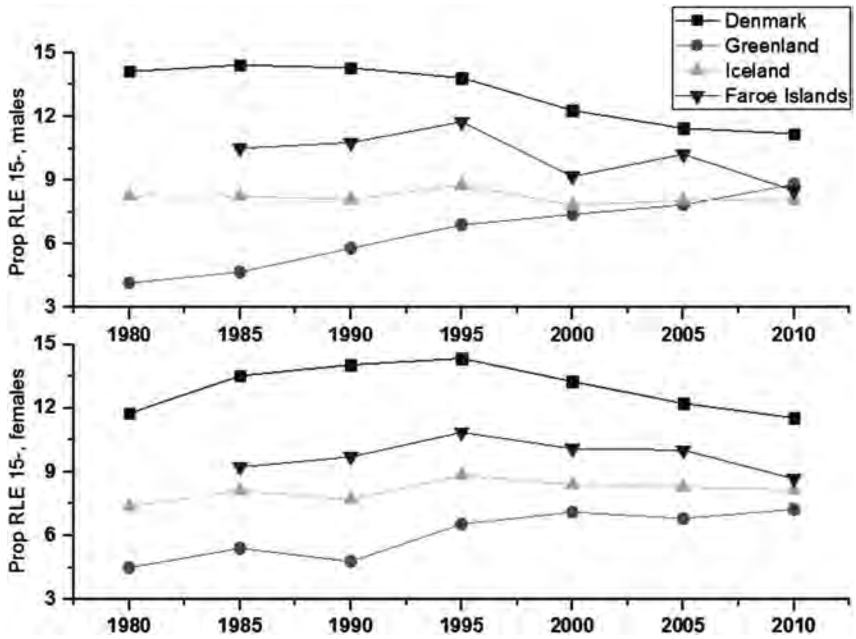
Denmark also has the smallest share of children in the population. The North Atlantic regions used to perform better in this regard, and more data can be seen in Appendix 1. At the same time, an intense wave of out-migration of young people and children in recent years has caused the islands' populations to age even further. If we compare 1980 to 2010, we see that the proportion of working-aged (15–59) and older (60+) people in the population increased by 0.9% and 5.5%, respectively, in the Faroe Islands, by 2.1% and 5.3% in Greenland, and by 3.4% and 3.3% in Iceland.

2.3 Proportion of older people

Focusing specifically on the proportion of older people in the age structure, we see that the chronological age-based methods indicate that the sex balance has changed in recent years. From 1980 to 2013, the share of men aged 60+ in the population grew from 4.5% to 12% in Greenland. In Iceland, this share had reached 12% by the 1980s. The number of Icelandic men aged 60+ increased by almost one-third over this period. In 2013, the Faroe Islands had the highest share in the region of men aged 60+ in the population (20.6%). Among women aged 60+, the fastest changes occurred in the Faroe Islands, where the share of older women in the population reached 23.2% in 2013. The share of women aged 60+ in the population reached somewhat lower values in Iceland (19%) and in Greenland (11.3%) in 2013. In Greenland, the shares of men and women aged 60+ were roughly the same in 1980, but by 2013, older men outnumbered older women. This is an unusual situation given that older women outnumber older men in most parts of the world. The explanations for this gender imbalance include the high rates of out-migration of women from the island since the beginning of the 1990s and the predominance of male-oriented employment sectors. Rauhut et al. (2008) also observed that the share of people aged 60+ in the population is relatively low in Greenland due to the shorter LE and the fact that many pensioners choose to settle in Denmark.

The related Prop 60+ measure refers to the proportion of people considered old when the average remaining lifespan in their age group is less than 15 years. Figure 3 illustrates the evolution of Prop RLE 15 proportions in the 1980–2010 period. When we weight the RLE of all age groups with the proportions of people belonging to those age groups in the population, the dynamics of population ageing are altered. We see changes for both sexes: Prop RLE 15 declines slightly in every territory, except in Greenland due to its lower LE. At the end of the period, the differences between the North Atlantic territories diminish noticeably, and the ratios, including the OADRs, start to converge. Hence, the historical ageing trends look different than they did when we were using the conventional definition of elderly people.

Figure 3:
Danish and North Atlantic proportions of the population with a remaining life expectancy of 15 years or less (Prop RLE 15) by sex, (%) of total population (1980–2010)



Note: The data are the authors' calculations based on population count and mortality numbers provided by Statistics Denmark, Statistics Greenland, Statistics Faroe Islands, and Statistics Iceland.

2.4 Dependency ratios

The old-age dependency ratio (OADR), a common measure of ageing, corresponds to the ratio between the number of older people and the total working-aged population (aged 15–59). The current OADRs were calculated based on the knowledge that the complementary measure, the young age dependency ratio, is higher in Iceland, Greenland, and the Faroe Islands than in other Nordic territories. For the middle-share ratios, there is, as mentioned above, an upwards trend in the migration of young, educated women to other economically prosperous areas and countries (Rasmussen 2011).

Over the study period, the highest OADR load for both sexes was in the Faroe Islands, followed by in Iceland. Greenland had the lowest OADR due to the relatively large share of young people in the age structure of its population. The speed of change of the ratio differed over the period, with the fastest growth occurring in the Faroe Islands, particularly among women. The OADR grew half as quickly in Greenland and in Iceland as in the Faroe Islands among women. Greenland's male population experienced relatively fast OADR growth. Topping the whole North Atlantic region was Denmark, where the indicator was two to three times higher than in Greenland.

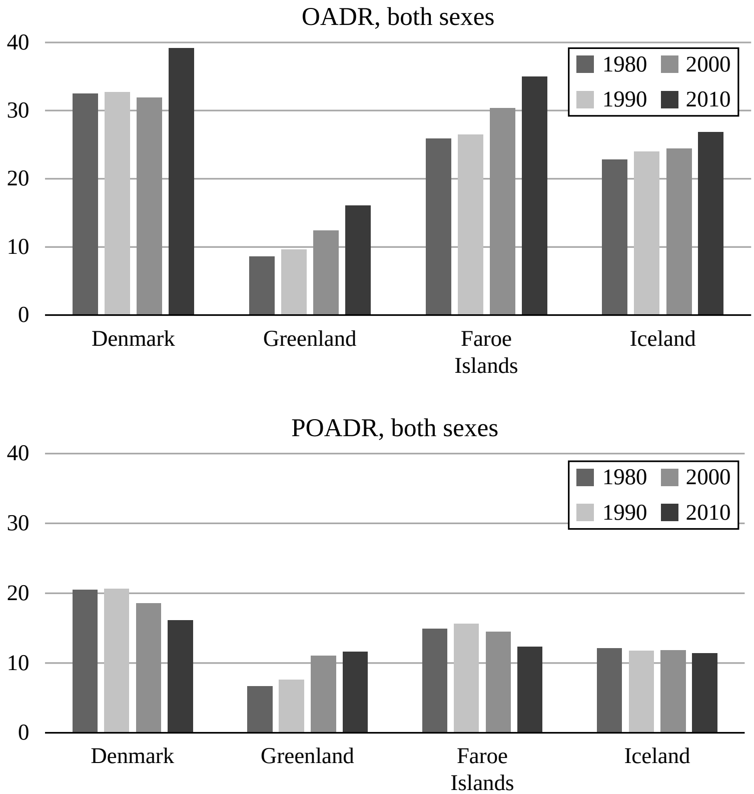
Given this pronounced growth in old-age dependency, as measured conventionally, over just over three decades, local governments and stakeholders may raise concerns about the sustainability of current welfare systems. However, it must be taken into account that, as people age, they tend to gain healthy years, and thus do not automatically become a burden on the health care and social welfare systems after the age of 60. These dependency ratios change when the prospective OADR is calculated, as both the numerator and the denominator are affected by the old-age threshold. In the prospective OADR, the old-age threshold is connected to the floating LE, rather than being set at age 60. Increases in the threshold age (RLE 15) reduce the number of people considered old, and hence increase the share of people of working age. Figure 4 illustrates that the dependency ratios are much lower using this approach than using the chronological approach. The POADRs for both sexes and in all areas increase less rapidly than when the traditional OADR is applied. Moreover, the figure shows that the POADR has been slowly decreasing in most of the North Atlantic since the 1990s, whereas the OADR has been growing.

By replacing the number of people aged 60 years or older in the calculations with the number of people older than the specific old-age threshold, we provide a new type of evidence regarding societal dependency in old age, adjusted to longevity and health transformations. This exercise showed a decrease in dependency in Denmark and the Faroe Islands for both sexes, and for males in Iceland. One exception is Greenland, where the POADR has been growing. This trend is related to the accelerating ageing and the relatively early stage of the health and demographic transition of the Inuit population ("natives born in Greenland" in Statistics Greenland) who made up 89% of the total population in Greenland in 2015 (Statistics Greenland 2016).

2.5 Ageing indices

It is important to address the ageing index (AI) when analysing changes in age structure, as it is greatly influenced by survival and fertility rates. The composite AI shows the interrelations between the old and the young age groups, and estimates how fast a population is ageing by calculating the number of people aged 60+ for every 100 young people under age 15 (the elder-child ratio). Figure 5 shows that the AIs generally increased among the populations in the North Atlantic between 1980 and 2010. The Faroe Islands had the highest AI for both sexes, followed by Iceland, with Greenland lagging considerably behind. The AIs of the Faroe Islands and Iceland grew rapidly in recent years due to the sharp rise in the proportion of the population with higher education, which is an important factor in falling birth rates, among other things. When comparing chronological and prospective AIs, it is

Figure 4:
Chronological and prospective old-age-based dependency ratios in Denmark and the North Atlantic region, sexes combined, 1980–2010



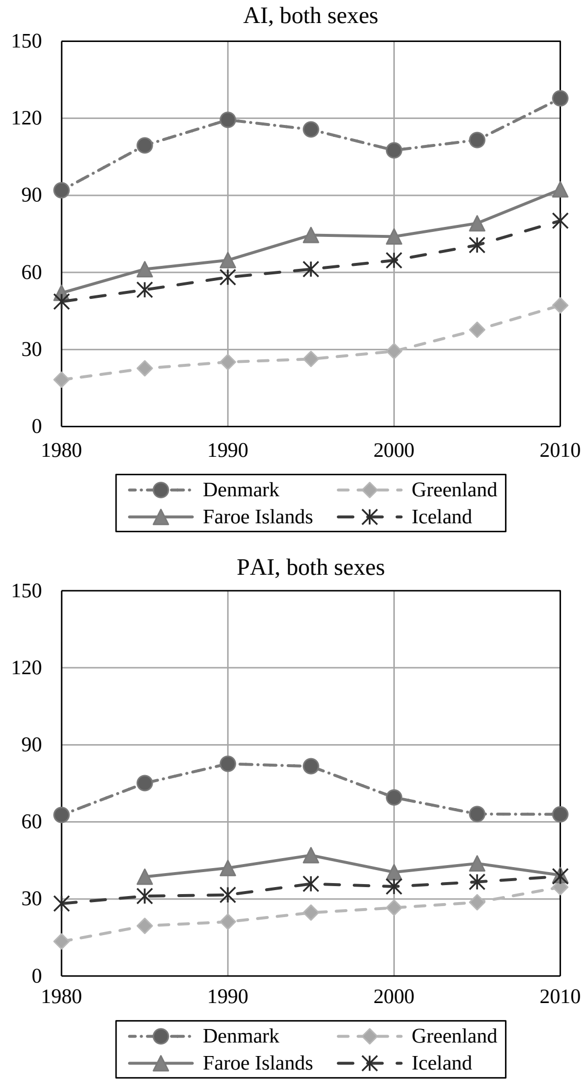
Note: OADR: Old-age dependence ratio, POADR: Prospective old-age dependency ratio. The data are the authors' calculations based on mortality numbers provided by Statistics Denmark, Statistics Greenland, Statistics Faroe Islands, and Statistics Iceland.

interesting to observe that the PAI values rose more slowly than the AI values, and that there were also some downwards trends, such as in the Faroese population after 1995. These developments led to a convergence (particularly among males) in the PAI rates by 2010 across the three North Atlantic territories (Figure 5).

3 Conclusion

The ageing variations across the North Atlantic considered in this study are determined by broad demographic drivers:

Figure 5:
Chronological and prospective old-age-based ageing indices in Denmark and the North Atlantic region, sexes combined, 1980–2010



Note: AI: Ageing index, PAI: Prospective ageing index. The data are the authors' calculations based on population counts and mortality numbers provided by Statistics Denmark, Statistics Greenland, Statistics Faroe Islands, and Statistics Iceland.

- Iceland and the Faroe Islands have one of the highest life expectancies in the world (82 years in 2015) and the lowest mortality levels in the world, whereas life expectancy in Greenland lags eight years behind (74 years in 2015).

- The TFR has historically been higher in the North Atlantic than in nearly every other country in Europe, but as was noted in the results and discussion sections, it has been falling since the end of the 1960s: i.e., the average TFR across the three territories declined from three in 1970 to two in 2015. This value is around the replacement level and above the Danish national average.
- A powerful ageing driver within this geography is the meaningful out-flow of college-bound youth (representing 15% of youth emigration in the age group 20–24 in the Faroe Islands in 2015), and of educated people in older age groups, especially from rural areas (Statistics Faroe Islands 2016). This trend started to accelerate in the 2000s, and was accompanied by large waves of out-migration after the fishery/banking crises. In such conditions, ageing can exacerbate the challenges faced by rural and fishery communities, acting in concert with factors such as limited access to public services and transport, and decreasing income levels.

Following the study aims outlined in the introductory part of the paper, and based on the data summarised in Appendix 1, the results shed light on the oldest and the youngest, and the fastest and the slowest areas of ageing. The traditional measurements indicate that there has been an explicit upwards trend in ageing in all of the North Atlantic territories except in Denmark, where the MA and the OADR decreased in 1990–2000 and the AI decreased until 2010. In 2010 the most advanced ageing was found for the Faroese population, with Greenland lagging far behind. However, from 1980 to the present, Greenland (particularly the male population) has been experiencing the fastest ageing according to chronological measures, with the indices' values increasing two- to threefold. The trends in ageing in Greenland are also distinct in terms of sex differences, with older men outnumbering older women, which is rare worldwide. Meanwhile, the traditional indicators showed that Iceland has been ageing less rapidly, with its rates occupying a middle position between those of its two neighbours. Moreover, according to the chronological indices, the ageing rates in the North Atlantic territories have not been converging, but have instead been developing in parallel, while keeping the same ranking throughout the period.

The results of the prospective ageing indicators differed markedly from those of the chronological indicators. The prospective indicators showed that the ageing rates of the North Atlantic territories have been converging, and had reached almost the same degree of ageing by the 2010 observation, particularly among men. These findings diverge not just from those of traditional measurements of ageing dynamics, but from findings for some other regions of the Arctic, such as for the North American Arctic (Alaska and the Canadian North), where a high degree of cross-territorial divergence has been found (Emelyanova 2015). The ranking of the territories also changed. While the Faroe Islands had the highest chronological ageing rates, Greenland had the highest prospective estimates in 1980 and 2010 (e.g., PMAs). The prospective approach also showed a slower pace of ageing at several points in time. For Iceland and the Faroe Islands, this process even appeared to be reversed in the most recent decade, signifying a so-called population rejuvenation. A rejuvenation trend was found when the POADR rates (2000s) were applied to these two territories, and the Prop RLE 15 was shown to have declined for males in Iceland and in the Faroe Islands over the 1980–1990 period. Similar trends in the PAI, the PMA, and the Prop RLE 15 after the 2000s were found among Faroese women. Almost all of the indices of prospective ageing for Denmark were shown to be decreasing.

The future path of ageing in the North Atlantic communities needs to be continually monitored and forecasted, as smaller populations can experience greater fluctuations and more abrupt changes in terms of age structure and population size than larger populations. The way ageing is measured also needs to be taken into account, as we have shown for the case of the North Atlantic in this study. The prospective measurement of ageing indicates that societal ageing is not developing as quickly or as linearly as the chronological approach has shown; thus, our understanding of the consequences of ageing and our responses to this phenomenon may need to be reconsidered.

References

Aasbrenn, K 1989. Uttynningssamfunnet. Det demografisk uttynnede - men ikke avfolkede - utkantsamfunn in. *Tidskrift for samfunnsforskning* 30(5/6): 509–519.

Danilova, R., E. Golubeva and A. Emelyanova 2011. Demographic aspects of the social safety of the elderly population in the Barents Euro-Arctic region. *Advances in Gerontology* 1(3): 195–202.

Denton, F. and B. Spencer 2000. Some demographic consequences of revising the definition of 'Old' to reflect future changes in life table probabilities. SEDAP Research Paper 2000–22. Hamilton, Canada: McMaster University.

Dustmann, C. and G. Albrecht 2011. Migration and education. Discussion Paper 2011–11. Norface Research Programme on Migration, Department of Economics. London: University College London.

Emelyanova, A. and A. Rautio 2012. Ageing population in the Barents Euro-Arctic region. *Journal of European Geriatric Medicine* 3(3): 167–173.

Emelyanova, A. and A. Rautio 2013. Perspectives for population ageing in the Russian North. *Journal of Population Ageing* 6(3): 161–187.

Emelyanova, A. 2015. *Cross-regional analysis of population aging in the Arctic*. Academic doctoral dissertation. Acta Universitatis Ouluensis D Medica 1326, Juvenes Print Tampere, 2015, pp. 1–94. http://herkules.oulu.fi/isbn9789526210049/isbn9789526210049.pdf, accessed on 23 August 2016.

Emelyanova, A. and A. Rautio 2016. Population diversification in demographics, health, and living environments: the Barents Region in review. *Nordia Geographical Publications Yearbook 2016*. Forthcoming.

Foss, O. and D. Juvkam 2005. Patterns of demographic ageing and related aspects in the northern peripheries. Nordregio Report 2005–2. Stockholm: Nordregio.

Gløersen, E., A. Dubois, A. Copus and C. Schürmann 2005. Northern peripheral, sparsely populated regions in the European Union. Nordregio Report 2005–04. Stockholm: Nordregio.

Golubeva, E. and R. Danilova 2011. Improving the social safety of elderly population in the system of social work on sparsely populated areas of European North of Russia. *Medico-Biological and Socio-Psychological Problems of Safety in Emergency Situations* 4: 85–88.

Hamilton, L. and A. Mitiguy 2009. Visualizing Population Dynamics of Alaska's Arctic Communities. *Arctic* 64(4): 393–398.

Hansen, K., R. Rasmussen and J. Roto 2011. Demography in the Nordic countries – a synthesis report. Nordregio Working Paper 2011–09. Stockholm: Nordregio.

Hansen, K., R. Rasmussen, J. Roto and C. Fredricsson 2012a. Megatrends in the Arctic – new inspiration into current policy strategies. Nordregio Working Paper 2012–08. Stockholm: Nordregio.

Hansen, K., R. Rasmussen and J. Roto 2012b. Nordic perspectives on demography – a background report for the project on coastal societies and demography. Nordregio Working Paper 2012-12. Stockholm: Nordregio.

Johnston, R. 2016. Historical abortion statistics. http://www.johnstonsarchive.net/policy/abortion/index.html, accessed on 27 September 2016.

Larsen, J. N. and G. Fondahl, eds 2014. *Arctic human development report. Regional processes and global linkages*. Copenhagen: Nordic Council of Ministers.

Leeson, G. 2002. The changing face of the population in Europe. Nordregio Working Paper 2002–02. Stockholm: Nordregio.

Lewis, J. 2013. The future of successful ageing in Alaska. *International Journal of Circumpolar Health*. doi.org/10.3402/ijch.v72i0.21186.

Lutz, W., W. Sanderson and S. Scherbov 2008. The coming acceleration of global population ageing. *Nature* 451: 716–719.

Moore, E. and M. Pacey 2004. Geographic Dimensions of Ageing in Canada, 1991–2001. *Canadian Journal on Ageing/La Revue Canadienne du Vieillissement* 23(suppl.): 5–21.

Hörnström, L. and J. Roto 2013. A Nordic 'Agequake'? Population Ageing in Nordic Cities and Regions. Nordregio News Issue 2013–03, Stockholm: Nordregio. http://www.nordregio.se/en/Metameny/Nordregio-News/2013/Nordic-Population-Ageing–Challenge-and-Opportunity/Context/, accessed on 24 August 2016.

Nummela, O., M. Seppänen and A. Uutela 2011. The effect of loneliness and change in loneliness on self-rated health (SRH): a longitudinal study among ageing people. *Archives of Gerontology and Geriatrics* 53(2): 163–167.

Rasmussen, R. 2005. *Analysis of hunters and fishermen in Greenland*. Grønlands Hjemmestyre - Direktoratet for Fangst og Fiskeri og NORS – Nordatlantiske Regionalstudier. Roskilde: Roskilde Universitets Center.

Rasmussen, R., ed. 2011. *Megatrends*. Copenhagen: TemaNord, Nordic Council of Ministers.

Rauhut, D., R. Rasmussen, J. Roto, P. Francke and S. Östberg 2008. The demographic challenge to the Nordic countries. Nordregio Working Paper 2008–01. Stockholm: Nordregio.

Roto, J., J. Grunfelder and L. Rispling, eds. 2014. *State of the Nordic region 2013*. Stockholm: Nordregio.

Roto, J. and R. Rasmussen 40 years of population change in West Norden. http://www.nordregio.se/Metameny/About-Nordregio/Journal-of-Nordregio/Journal-of-Nordregio-2010/Journal-of-Nordregio-no-3-2010/40-years-of-population-change-in-West-Norden/, accessed on 24 August 2016.

Sanderson, W. and S. Scherbov 2008. Rethinking age and ageing. *Population Bulletin* 63(4): 1–20.

Sanderson, W. and S. Scherbov 2010. Remeasuring Ageing. *Science* 329(5997): 1287–1288.

Sanderson, W. and S. Scherbov 2013. The characteristics approach to the measurement of population ageing. *Population and Development Review* 39(4): 673–685.

Scherbov, S. and W. Sanderson 2016. New approaches to the conceptualization and measurement of age and aging. *Journal of Aging and Health* 28(7): 1159–1177, accessed on 16 December 2016.

Statistics Faroe Islands 2016. http://www.hagstova.fo/en, accessed on 23 August 2016.

Statistics Greenland 2016. http://www.stat.gl/default.asp?lang=en, accessed on 23 August 2016.

Statistics Iceland 2016. http://www.statice.is/, accessed on 23 August 2016.

United Nations. 2015. *World Population Ageing 1950–2050*. New York: Population Division DESA. (ST/ESA/SER.A/390). http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf, accessed on 16 December 2016.

Wilson, D., J. Osei-Waree, J. Hewitt and A. Broad 2012. Canadian provincial, territorial, and federal government aging policies: A systematic review. *Advances in Aging Research* 1(2): 38–46.

World Health Organization. 2011. Life expectancy ranking. http://www.who.int/gho/mortality_burden_disease/life_tables/situation_trends_text/en/, accessed on 21 December 2013.

Appendix

Table A.1:
Population ageing indicators for the North Atlantic region by sex, 1980–2010

Year	Sex	MA	PMA	Prop 60+	Prop RLE 15	OADR × 100	POADR × 100	AI × 100	PAI × 100	Age 15
Greenland										
1980	Males	24.72	37.13	4.51	4.17	6.76	6.14	15.67	13.32	61.02
1990		28.53	40.49	5.45	5.81	7.74	8.26	22.60	24.42	59.23
2000		32.56	42.53	7.34	7.40	10.96	11.09	28.52	28.54	59.74
2010		35.08	42.84	10.85	8.80	16.12	12.78	49.71	39.45	61.90
1980	Females	22.52	33.51	6.54	4.50	10.55	7.22	20.74	13.55	64.63
1990		26.81	36.97	7.54	4.78	11.59	7.00	27.59	17.83	64.73
2000		29.59	41.69	8.66	7.10	13.84	11.09	30.13	24.64	62.54
2010		32.01	40.52	10.59	7.23	16.12	10.57	44.61	29.73	64.68

Table A.1: Continued

Year	Sex	MA	PMA	Prop 60+	Prop RLE 15	OADR × 100	POADR × 100	AI × 100	PAI × 100	Age 15
Iceland										
1980	Males	26.30	31.95	12.24	8.25	20.53	12.98	43.51	29.34	65.80
1990		29.38	32.52	13.26	8.08	21.63	12.16	52.11	31.77	66.89
2000		32.13	33.12	13.83	7.83	22.16	11.45	58.12	32.90	68.84
2010		34.27	33.92	15.73	8.07	24.94	11.41	74.12	38.03	68.99
1980	Females	27.34	30.94	14.63	7.36	25.17	11.25	53.74	27.03	70.41
1990		30.25	32.69	15.74	7.70	26.36	11.37	64.09	31.37	70.85
2000		32.48	34.97	16.27	8.41	26.73	12.23	71.20	36.78	71.06
2010		35.31	34.54	17.78	8.15	28.87	11.45	86.12	39.50	72.39
The Faroe Islands										
1985	Males	28.39	34.54	13.70	10.50	23.48	16.40	49.05	41.32	64.51
1990		30.39	35.46	14.04	10.78	22.76	16.60	57.75	44.34	64.24
2000		33.96	35.34	15.73	9.18	25.88	13.63	67.05	39.13	68.17
2010		36.71	36.63	18.85	8.50	31.70	12.18	87.02	39.25	70.00
1985	Females	28.30	33.02	15.74	9.23	28.28	14.17	54.97	35.94	68.74
1990		31.06	33.74	17.53	9.71	30.21	14.75	71.76	39.75	69.22
2000		35.15	35.41	19.58	10.09	34.84	15.37	80.85	41.68	72.14
2010		38.18	35.34	21.58	8.68	38.32	12.55	97.58	39.26	74.46
Denmark										
1980	Males	33.00	43.51	17.16	14.12	28.14	21.89	78.40	66.17	63.12
1990		35.71	45.64	17.74	14.28	27.51	21.02	99.65	80.21	63.69
2000		37.23	45.23	17.34	12.29	27.29	17.91	90.76	64.29	65.25
2010		39.60	45.09	21.33	11.19	35.57	15.96	114.07	59.84	67.89
1980	Females	35.26	36.89	21.48	11.75	36.94	19.05	105.50	59.18	68.65
1990		38.42	39.86	22.97	14.04	37.97	20.21	139.12	85.01	68.97
2000		39.39	39.78	22.03	13.25	36.56	19.19	124.28	74.75	69.50
2010		41.28	39.47	24.73	11.54	42.80	16.27	141.38	66.00	71.14

Note: MA/PMA – (prospective) median age, PMA, refers to Iceland in 2005 as a reference year; Prop 60+ is the share of people aged 60 and older; Prop RLE 15 is the share of people with a remaining life expectancy of 15 years or less; OADR/POADR – (prospective) old-age dependency ratio; AI/PAI – (prospective) ageing index; Age 15 is the age at which the remaining life expectancy is equal to 15. Greenland's data are provided for a five-year average only, as our calculations are based on mortality tables downloaded from Statbank of Statistics Greenland, provided for a five-year interval only. The table indicators refer to the periods of 1977–81, 1987–91, 1997–2001, and 2007–11.

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Certain characteristics of population ageing using a prospective approach: Serbia as a case study

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Abstract

The aim of this research is to show trajectories of population ageing in Serbia according to chronological and prospective criteria. The data used are from the complete period life tables published around the census years from 1953 to 2011. The emphasis is on the most recent period, since these data allow us to incorporate a regional dimension into the study, and to carry out the analysis at the municipal level. Throughout this study period, the prospective age threshold in Serbia was below the retrospective threshold; as a consequence, the proportion of people with a life expectancy of 15 years or less was consistently higher than the share of people aged 65 or older. Only the most recently available data for 2010/2012 indicate that the share of the population with a life expectancy of 15 years or less was the same as the share of the population aged 65+, albeit with uneven contributions by the male and female populations. Indeed, the use of the prospective approach highlights the unfavourable mortality conditions in Serbia, which are not made clear when only the chronological approach to population ageing is applied.

1 Introduction

Over the course of the last half of the 20th century, the levels and the directions of certain demographic forces that shape the populations of different countries changed substantially. These demographic shifts are still clearly visible in the former Eastern Bloc countries, where long-term developments in fertility, mortality, and migration have had profound effects on the current demographic structure of the population. As the focus of our research is Serbia, it is necessary to begin by noting the dynamic political and economic changes that have affected the country's

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demography in recent decades. Between 1992 and 2006, the political status of Serbia shifted: Serbia went from being one of the six republics in the Socialist Federal Republic of Yugoslavia (Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Slovenia, and Serbia) to being one of the two republics in the State Union of Serbia and Montenegro, to becoming an independent state. Meanwhile, the political influence that Yugoslavia (and its constitutive nations) had exerted as a part of the Non-Aligned Movement was diminished after the breakup of the federal union. As Yugoslavia dissolved, Serbia transitioned from having a planned economy to having a market economy. Large segments of the Serbian population found it very difficult to adapt to these abrupt shifts. Additionally, the move from general stability during the Yugoslav era to a period characterised by rapid socioeconomic change interacted with the specific features of the Serbian population. As conflicts between the Yugoslav federal republics began in 1991, a negative chain of events started, including a breakdown of trade relations, the imposition of UN financial and political sanctions in response to the Serbian role in the Yugoslav Wars, the influx of numerous refugees (particularly ethnic Serbs) from neighbouring regions, a surge in the number of internally displaced persons, the emigration of highly educated citizens, and the NATO bombing of Yugoslavia (1999). These events have all had an impact on the fertility and mortality levels and the population structure of Serbia in recent decades.

2 Sources of data and methodological limitations

Before presenting our analysis of various demographic processes in the Serbian population, we should mention some important technical and methodological issues. First, we note that there are issues related to changes in the definition of total population in the censuses in Serbia, as these irregularities may have (minor) effects on the research results of this paper. Unfortunately, it was not possible to eliminate such inconsistencies. In line with international census recommendations, Serbia adopted a new definition of citizen in 2002. Under this definition, individuals who lived or worked outside of Serbia in the previous year were not considered part of population. As this change had a large impact on the census results, caution should be used in interpreting the census data. Starting in the 1960s, large numbers of Serbian workers were migrating to other European countries. In a break with previous practice, the censuses of 1971, 1981, and 1991 counted these migrants and their family members as citizens of Yugoslavia (and Serbia), regardless of the duration of their stay abroad. Thus, even though some of these so-called "temporary workers" had been living abroad for more than 30 years, they were still considered part of the Serbian population.

The most recent census in 2011 brought additional changes in definitions. When estimating the total number of people in a given area, the concept of the "usual population" was used for the first time. The purpose of this new concept was to more precisely define population, but with an emphasis on the regional distribution;

thus, this change probably had only a minor impact on the total population numbers. However, these usual population estimates made it easier to evaluate the very dynamic migration patterns in the territory of Serbia between settlements and regions (mostly towards Belgrade). Under the definition of this term, a person is considered to be a resident of the place in which he/she alone (in case of a one-person household) or with members of his/her household spends most of his/her time (i.e., where the person sleeps); regardless of his/her registered place of residence. Thus, the total population of a certain place includes the individuals who had lived in that place continuously for at least one year before the time the census was taken, as well as the individuals who had lived in that place for less than 12 months, but with an intention to stay there for at least one year (SORS 2012). This concept could be important for our research since we are using complete life tables for the municipal level. In addition, unlike in the previous censuses, there was no column with unknown age in the 2011 census.

Another change that should be noted is related to the treatment of internally displaced persons; i.e., the people who migrated from Kosovo and Metohija after the 1999 NATO bombing. The 2002 census had a special questionnaire for this group, and they were not added to the total population in the new population balance. Yet the methodology used in the 2011 census counted these individuals as part of the resident population, adding them to the total number of enumerated citizens. An additional limitation of the 2011 census is the potential for under-coverage due to the boycott of the census by members of the Albanian ethnic community in three municipalities. However, life tables for those municipalities were calculated by drawing upon numerical and structural statistics. All of these inconsistencies had some impact on data quality, but the major trends and patterns in the population can be distinguished.

For the purpose of the analyses, we used seven consecutive published life tables for the years around the censuses for Central Serbia and Vojvodina. We were unable to use published data for the Republic of Serbia because over the course of the last decade, Kosovo and Metohija declared independence, which made most of the statistical data unavailable. This problem persisted for a long period of time. For example, vital statistics are not available from 1998, and the 1991 census gathered only limited data on the population living in Kosovo and Metohija. In order to create comparable time series, we had to make some compromises, while keeping in mind the importance of obtaining correct and accurate data that are comparable in terms of time and territory. To incorporate the territorial changes that had occurred, we used additional computation of complete life tables for the territory of the Republic of Serbia (Central Serbia and Vojvodina without Kosovo and Metohija). This approach to administrative-territorial changes and data availability did not affect the final results of the life tables. It is worth mentioning that because the method used for the computation of complete life tables did not change (Becker–Zeuner method), methodological uniformity was assured. We started with the first available complete life tables created for the period 1952–1954, and then referred to the life tables for 1960/1962 and 1970/1972. In all of these tables the data were available for males and females, but not for the total population. The rest of the published life tables are for the years 1980/1981, 1990/1992, 2001/2003, and, finally, 2010/2012.

3 Drivers of Population ageing in Serbia

Despite the many recent disruptions to Serbian society, some demographic trends in the country have been relatively steady. For example, the period total fertility rate (TFR) has been falling for decades, from relatively high levels during the post-World War II baby boom around the 1950s (3.1 in Central Serbia and 2.8 in Vojvodina), to lowest-low levels in recent years (around 1.3). The current tempo-adjusted TFR is 1.6,[1] which is still below replacement level. Age-specific mortality also underwent a transition: whereas infant mortality levels were high half a century ago, they are much lower today due to medical advances and better access to healthcare. Improvements in life expectancy were very rapid in the decades after World War II, and are clearly visible on Graph 1, with female life expectancy rising faster than male life expectancy. These positive trends have, however, slowed down in recent decades. The stagnation in life expectancy in the 1990s reflects the harsh conditions the population endured during the transition to a market economy and the years of war and economic sanctions. While the most recent available data show some tangible improvements in mortality, Serbia continues to lag far behind other countries in terms of life expectancy, and has considerable room for further improvement.

Additional structural changes (urbanisation, deruralisation, industrialisation, and the expansion of educational opportunities) have resulted in a decrease in fertility and in the concentration of mortality at older ages. The emigration of "temporary workers" in the 1960s affected the population structure, as the option of family reunification enabled whole families to leave the country. The different characteristics of the waves of migration over the past three decades also modified the age structure of the population: for example, whereas the ages of the immigrant refugees during the 1990s reflected the age structure of the endogenous population, most of the emigrant workers were young. Consequently, the shares of different age groups in the population have fluctuated. Generally, the share of younger people in the population has fallen, while the share of older people in the population has risen. All of these processes have reinforced the pronounced population ageing trend in Serbia, which is affecting various societal spheres.

In order to cover the numerous changes that happened in Serbian spatial units as a result of international recommendations, and since territorial units were recently brought into line with the NUTS nomenclature, we present a comprehensive overview (Table 1) of the total number of people aged 65 and older, and of their share in the total population. All of the censuses before the last one showed a

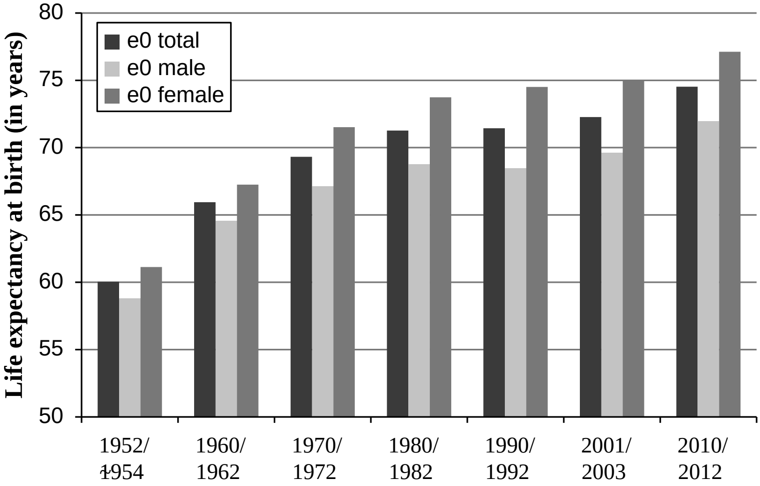
1 Author's calculation, there are no official data on this indicator.

Table 1:
Total number and share of people aged 65 and older, census years

Census year	1948	1953	1961	1971	1981	1991	2002	2011
	Total number of 65+							
Serbia (without Kosovo)	324950	384061	446628	650828	801959	895615	1240505	1250316
Vojvodina	105785	123080	139946	189585	229962	238051	315185	316538
Central Serbia	219165	260981	306682	461243	571997	657564	925320	933778
Belgrade	14554	21070	45323	87101	122343	158434	247029	271762
NUTS1 Serbia-South*	204611	239911	261359	374142	449654	499130	678291	662016
NUTS1 Serbia-North**	120339	144150	185269	276686	352305	396485	562214	588300
	Share of 65+ in total population							
Serbia (without Kosovo)	5.61	6.23	6.69	9.04	10.38	11.45	16.54	17.40
Vojvodina	6.45	7.25	7.54	9.71	11.30	11.82	15.51	16.39
Central Serbia	5.28	5.85	6.36	8.78	10.04	11.32	16.93	17.77
Belgrade	2.29	2.88	4.81	7.20	8.32	9.89	15.67	16.38
NUTS1 Serbia-South*	5.81	6.43	6.73	9.26	10.64	11.87	17.44	18.41
NUTS1 Serbia-North**	5.29	5.93	6.62	8.75	10.05	10.96	15.33	16.38

Source: Devedzic, Stojilkovic Gnjatovic (2015) *Central Serbia without Belgrade; ** Vojvodina and Belgrade region

Graph 1:
Life expectancy of total population, around census years



territorial division that included Central Serbia and two autonomous provinces: namely, Vojvodina and Kosovo and Metohija. The census held in 2011 was harmonised with European nomenclature of territorial units of statistics (NUTS). It is not possible to compare the same areas across censuses because in the 2011 census the region of Belgrade was no longer considered a part of Central Serbia, but was instead included in NUTS 1 Serbia-North together with Vojvodina. Moreover, Central Serbia was no longer a viable term in the 2011 census, since most of the previous territory was called Serbia-South (three regions: Southern and Eastern Serbia, Western Serbia and Sumadija, and Kosovo and Metohija).

Even though the share of older people in the population had been rising with each consecutive census, it is important to highlight that the greatest increase was observed between the censuses held in 1991 and 2002. The hardship and the turmoil the population in Serbia endured during the 1990s are partially reflected in census data showing that over a period of just11 years (1991 to 2002), the share of people aged 65 and older in the population increased by an additional five percent. The last census confirmed the continuation of this trend, but at a slower rate. Migration has played a large role in population ageing trends. Since the middle of the 20th century, Serbians have been migrating from rural to urban settlements. Initially, this process was mainly related to the industrialisation of the country during the 1960s and the 1970s. As a result of this shift, many rural areas became depopulated, and large geographic areas of Serbia experienced unprecedented levels of demographic ageing. Following the economic transition in the 1990s, another trend emerged, with people moving from medium-sized cities to the biggest regional centres. Belgrade has always been appealing to migrants, but the tendency to move to the capital is fading as the population ages. Moreover, while the Belgrade region has long had the youngest population, its age structure has been catching up with that of the rest of Serbia over the past two decades. Today, the worst demographic situations are found in the municipalities without urban settlements, and those are mostly located alongside the borderline with the neighbouring countries. Based on a map that shows the share of older people in the population across settlements of varying sizes, Devedzic and Stojilkovic Gnjatovic (2015) concluded that bigger (mostly urban) settlements are younger than smaller (mostly rural) settlements. If we look at the share of people aged 65 and older in the population, it appears that Serbia South is slightly older than Serbia North; a topic we will explore later.

4 Emergence of a new thought on population ageing

Does being 65 mean being old? This is a hard question to answer. There is a great deal of evidence that the definition of "old" is changing over time and place, especially since today's elderly people differ from older people of previous decades in terms of their health and their life styles. Still, while these changes that are intuitively easily understood, measuring them represents a methodological challenge. To provide us with a more precise understanding of population ageing, Sanderson and Scherbov (2005, 2007, 2008, 2010) have suggested using a prospective approach that acknowledges variations in life expectancy. The advantage of this approach is that it considers "prospective age" as a dynamic category, and thus takes into account the improvement (or the deterioration) in life expectancy when measuring population ageing in a given country. This biometric (rather than chronological) approach is based on an operational definition of the old-age threshold, or the "prospective threshold", as the age at which life expectancy falls below 15 years. In elaborations of these ideas, three demographic indicators based on prospective age have been constructed: the (prospective) share of the elderly, the (prospective) median age, and the (prospective) old-age dependency ratio. This approach shows that in most developed countries, the share of people aged 65 and older in the population is larger than the share of people in the population who are going to live 15 years or less; but there are some countries on the other side of the spectrum. By defining α-ages, Sanderson and Scerbov (2014) provided some additional avenues for research on this topic.

For the purposes of this paper, we will present the assessment of population ageing using the prospective approach for Serbia. We also intend to show the trajectories of population ageing according to chronological and prospective criteria. This new paradigm of population ageing, which takes into account shifts in life expectancy, shows that Serbia lags behind other European countries in terms of improvements in health among the elderly. Indeed, the first publication that ranked countries on the basis of the prospective approach (Mamolo and Scherbov 2009) put Serbia in first place on a list of countries based on the share of the population expected to live less than 15 years (the arbitrary threshold chosen by the creators of the prospective approach). In subsequent publications of the European Demographic Data Sheet (2008, 2010, 2012, 2014), Serbia was still among the first three for this indicator.

Before we get to the prospective criteria of population ageing, we present an analysis of life expectancy at age 65 for the Serbian population. We conducted this analysis because it is clear that if life expectancy at age 65 is less than 15 years, then the number of people in this age group who are living less than 15 years is greater than the number of people aged 65+. If we consider the total population aged 65 and older in Serbia (Graph 2), we see that life expectancy among this group has been improving very slowly over the past six decades. A similar pattern holds for the rise in total life expectancy, except that in the case of 65-year-olds period life expectancy actually declined slightly between 1990/1992 and 2001/2003. Life expectancy among people aged 65+ has only recently started to show more marked improvements: the first time life expectancy among this group surpassed 15 years was in the last decade. Broken down by gender, we see that women generally have a higher life expectancy than men. Still, life expectancy among women aged 65+ has not shown steady improvement, and it even declined slightly during the 1990s. Nonetheless, the gains made by women are responsible for pushing this age group over the life expectancy threshold of 15 years: while the total population aged 65+ can expect to live 15.1 years, women have a life expectancy of 16.1 years, while men have a life expectancy of 13.8 years. According to Devedzic and Stojilkovic (2012), there are not only sex but regional differences, as both men and women in Central Serbia tend to live longer than their counterparts in Vojvodina.

We now look at the point at which the prospective threshold is reached, or the age at which life expectancy is 15 years or less. It is interesting to note that the prospective threshold was age 61 for the period 1952/1954, when population ageing was not regarded as a problem nor predicted to be such a pervading force. At that time, the older population was defined as people aged 60+. The perception of the onset of old age is frequently connected to the termination of economic activity and the attainment of pension rights, and this is also the case in Serbia. Until the 1990s in Serbia, the statutory pension age was 60 for men and 55 for women, but in line with current trends, the onset of old age was gradually reset. Changes in Serbian pension law in the 2000s led to an increase in the minimum retirement age to 65 for men and 60 for women. Thus, it appears that Serbia was in a better position in the 1950s than it is now, since it took more than half a century for the country to catch up even partially with the demographic developments in developed countries. It is appropriate to wonder whether future retirement policies will raise the retirement age further, and whether these demographic trends will be considered in such a move. While pensionable ages are being raised in some countries, the slow improvements in life expectancy could be a limiting factor in policy reforms in Serbia.

Given these trends in life expectancy among the Serbian population aged 65+ over the past six decades, it is not surprising that the prospective threshold was

Graph 2:
Life expectancy at age 65, around census years

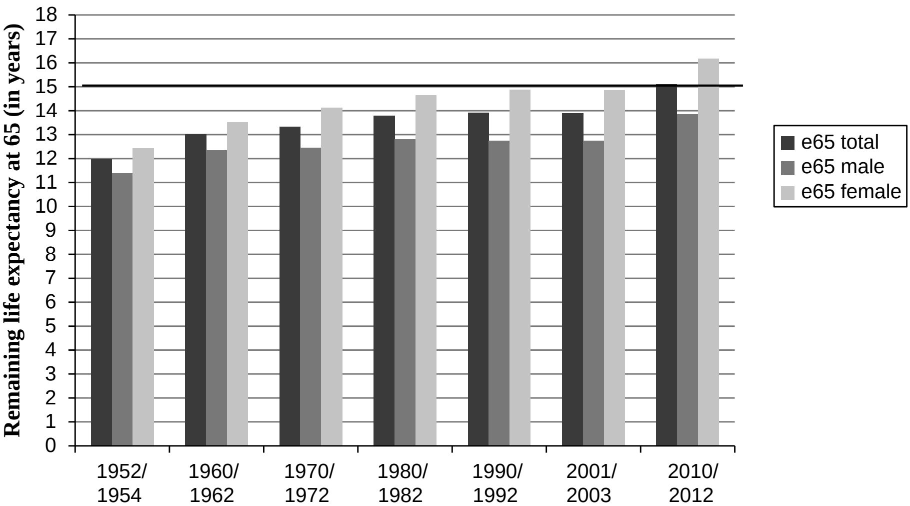


Table 2:
Prospective threshold, 1953–2011

	Serbia (without Kosovo)			Central Serbia			Vojvodina		
Year	Total	Male	Female	Total	Male	Female	Total	Male	Female
1952/1954	61.17	59.27	61.03	–	59.60	61.06	–	59.01	61.57
1960/1962	62.03	60.90	62.88	–	61.10	62.87	–	60.29	63.28
1970/1972	62.62	61.19	63.82	–	61.72	63.89	–	60.38	64.28
1980/1982	63.28	61.73	64.52	63.60	62.30	64.65	62.49	60.21	64.22
1990/1992	63.45	61.46	64.84	63.86	62.12	65.09	62.32	59.48	64.20
2001/2003	63.41	61.48	64.82	63.76	61.97	65.08	62.41	59.95	64.09
	Serbia (without Kosovo)			**Serbia – South**			**Serbia – North**		
2010/2012	65.14	63.23	66.51	65.11	63.43	66.38	65.19	62.98	66.70

Source: Based on Devedzic, Stojilkovic (2012).

below the limit that was widely accepted as the onset of old age for most of this period. The first time a regional subpopulation reached the prospective threshold of 65 was in 1990/1992 among the female population of Central Serbia. Given the general trends in male life expectancy, it is hardly surprising that no male regional population reached the prospective threshold of 65. On the other hand, the most recent available data show that the female population has made further advances.

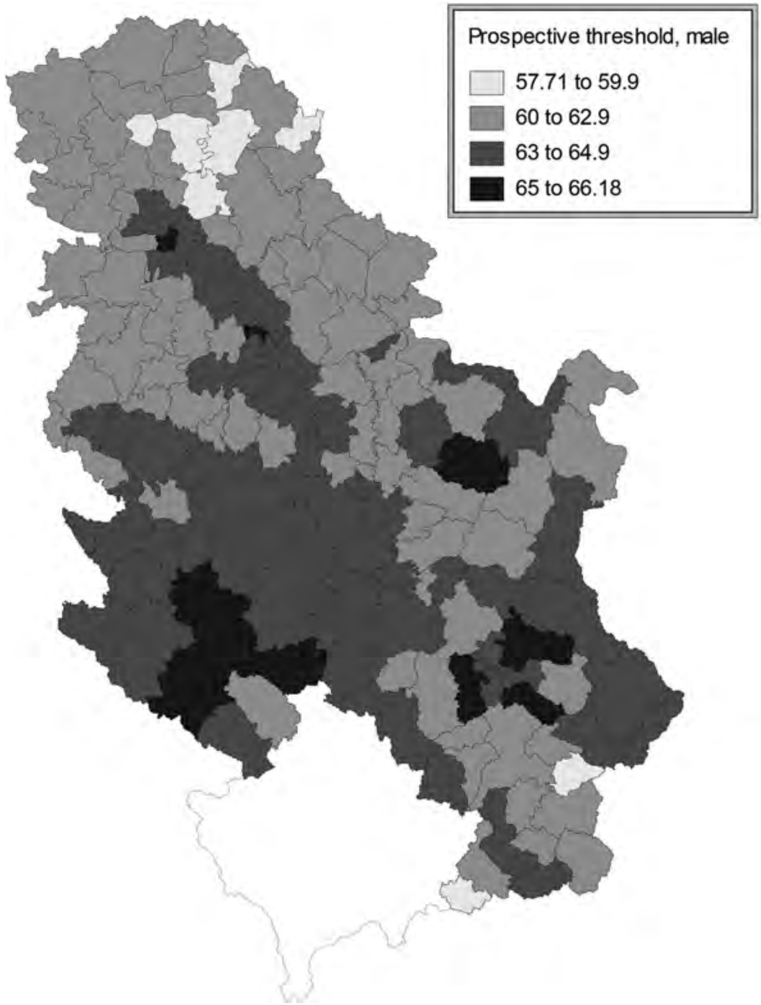
We have tried to shed some light on the various advantages of using the prospective approach rather than the traditional approach when examining population ageing. One very important dimension of demographic ageing is a regional aspect. In a country like Serbia, there is a high degree of centralisation of almost all social functions (the health care, industrial, service, and educational sectors are heavily concentrated in the Belgrade region), population ageing has to be placed in a spatial context. Studies that looked at the demographic features of aged 65 and older (Devedzic and Stojilkovic Gnjatovic 2015) have shown that these features vary in different parts of the country. Still, this kind of investigation does not provide us with information about the expected length of life of the older population. By incorporating the prospective approach into research on population ageing at the municipal level in Serbia, we were able to determine in which parts of the country the older population is long- (or short-) lived. First, we calculated the prospective threshold for all of the municipalities in Serbia using additionally processed period life tables. Map1shows the age at which the male population was expected to live 15 years or less in 2011. All of the municipalities in which this threshold was under age 60 were located in Vojvodina, with the exception of one in Southern Serbia (CrnaTrava, which is also known as one of the oldest municipalities in the country). It appears that Vojvodina had almost monotonically lower values, since of the municipalities between the regional centre of Novi Sad and the capital city of Belgrade, only one had a higher threshold. On the other hand, there were two isolated clusters in which men aged 65+ could expect to have an additional 15 years of life: one in Southern Serbia and the other in Western Serbia. This pattern calls for further investigation, but generally, municipalities in the mountainous parts of Serbia tended to have higher prospective thresholds, while municipalities located on the Vojvodina plain tended to have lower prospective thresholds.

The situation for the female population in 2011 was very different. The prospective threshold among women was under age 65 in only around one-tenth of all municipalities. This is a huge deviation from the male prospective threshold pattern, and clear proof that women tend to live longer than men in Serbia. However, before we interpret these findings as being positive for women, we should ask whether the women who live longer have a good quality of life. Moreover, these gaps between the sexes should be viewed in light of the marital (since women tend to marry older men), the educational (since women tend to have less education and higher rates of illiteracy), and the economic structures of the older population.

Our analysis of the prospective threshold can be extended by calculating the prospective share of the population living 15 years or less. When this indicator is compared with the traditional share of the population aged 65+, we get a more realistic picture of the trends in population ageing and the vitality of older people. This share depends on the prospective threshold and the population composition, or on the number of people in certain age groups.

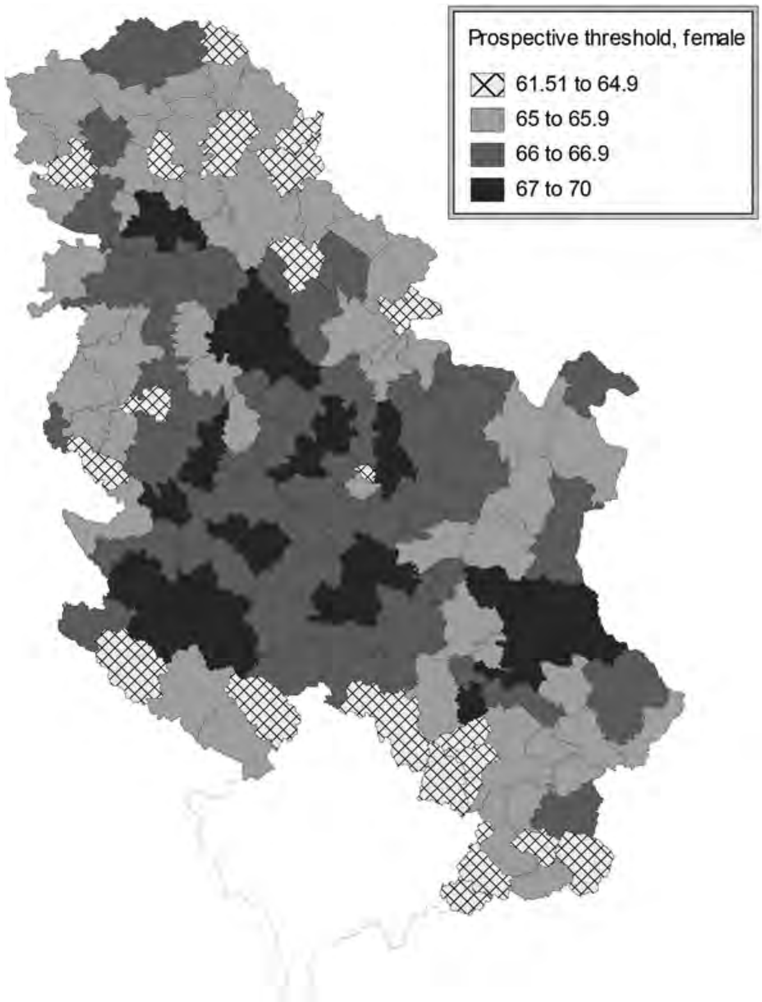
In Serbia, the very slow improvement in life expectancy among the older population is reflected in this comparison, because the prospective share was greater than the chronological share in all census years, except in the last one, when this

Map 1:
Prospective threshold, male population, 2011



difference was almost non-existent. Again, it is advisable to consider the absolute differences between the two approaches for the total, the male, and the female population (Graph 2). It is interesting to note that the life tables for the period 1980/1982 show the least variation when the share of the population with a life expectancy of 15 or less years is compared with the share of people aged 65+. However, the subsequent censuses showed even greater differences between the two analysed criteria, which highlights the societal changes that occurred around that time. The male population had lagged behind consistently, because the prospective

Map 2:
Prospective threshold, female population, 2011



share had been "occupying" larger population segments than the traditional share of older people. On the other hand, this difference was consistently smaller in the female population, among whom there was even a negative sign in 2010/2012, since the share of women aged 65 and older was greater than the share of women who were expected to live 15 years or less.

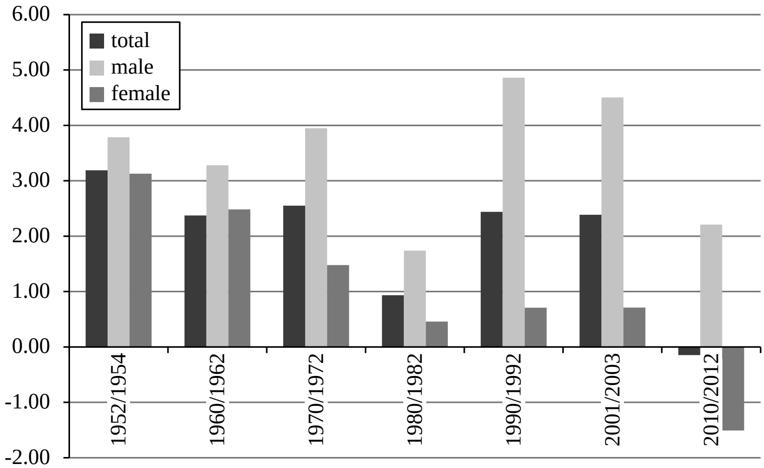
It is useful to add that these indicators are closely related to the population age composition, and that some demographic forces, like the fluctuation in fertility or in migratory movements, are affecting these outcomes. The relative shares of the

Table 3:
Proportion of the population with a remaining life expectancy of 15 years or less, around census years

	Serbia (without Kosovo)			Central Serbia			Vojvodina		
Year	Total	Male	Female	Total	Male	Female	Total	Year	Total
1952/1954	9.40	9.11	10.19	–	8.16	9.60	–	10.41	11.06
1960/1962	9.06	8.91	10.18	–	8.38	9.61	–	10.40	10.42
1970/1972	11.62	12.06	11.47	–	11.37	10.99	–	13.30	12.11
1980/1982	11.35	11.03	11.99	10.87	10.45	11.40	12.83	12.99	13.60
1990/1992	14.08	14.79	14.01	13.65	14.12	13.38	15.66	16.67	15.65
2001/2003	19.03	18.97	19.41	19.01	19.04	19.27	19.19	18.92	19.83
	Serbia (without Kosovo)			**Serbia – South**			**Serbia – North**		
2010/2012	17.58	17.59	18.45	18.61	18.44	19.50	16.53	16.74	17.36

Source: Based on Devedzic, Stojilkovic (2012).

Graph 3:
Absolute differences between the prospective and the chronological shares of the older population, around census years



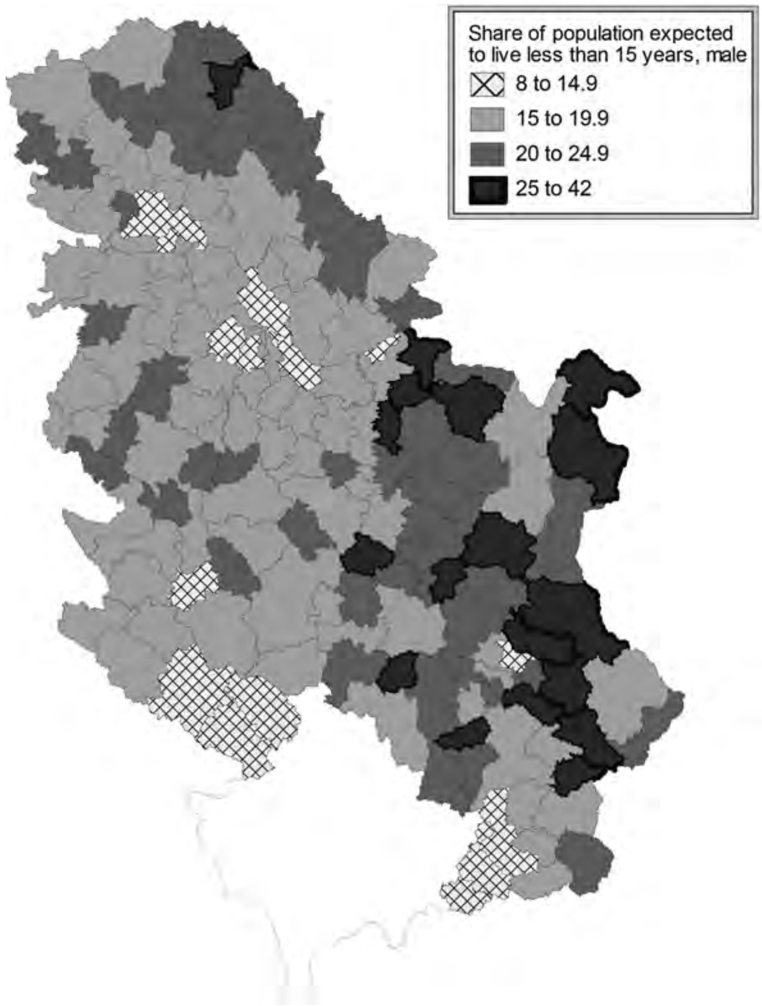
different population segments also should not be neglected. This factor seems to be especially important in the case of Serbia, because future changes in these indictors can be affected by a large baby boom generation. According to Stojilkovic (2010), individuals born between 1947 and 1956 can be classified as baby boomers. This generation is on the verge of becoming traditionally old, but the last census had been conducted just before the first boomers had their 65th birthdays. The substantial size of this generation could cause the share of older people in the population to increase, regardless of the criteria used.

In order to explore the options for (and the advantages of) applying the prospective approach in different settings, we calculated the share of the population expected to live 15 years or less for men and women in all Serbian municipalities. This enabled us to evaluate the spatial dimension of population ageing in an unconventional manner. When applied to the male population (Map 3), this new approach highlights some important features of the geographical distribution of the (prospective) older population in 2011. The municipalities with the lowest shares of men with a life expectancy of 15 years or less were either regional centres or municipalities with higher fertility rates. The three biggest cities in Serbia (Belgrade, Novi Sad, and Nis) had the smallest shares of the analysed indicator as a result of their more favourable age structures. On the other hand, in the municipalities in which fertility was above the Serbian average (Tutin, Sjenica, Novi Pazar, Bujanovac, and Presevo), the share of men with a life expectancy of 15 years or less was smaller than in the remaining municipalities. The municipalities that received the greatest number of refugees during the 1990s are all located in Vojvodina. However, since the population structure of these immigrants was similar to that of the endogenous population (co-ethnic migration), their presence did not have a substantial influence on demographic ageing, apart from adding to the total population numbers. It would seem that in Vojvodina, differences in old-age mortality played the major role in regional differences in (prospective) ageing. The worst situations were definitely in Eastern Serbia and in parts of Southern Serbia, where one-quarter of all men had a life expectancy of 15 years or less. This is a mountainous area that has been heavily affected by the rural to urban migration waves that have significantly modified the country's age structure. Thus, these small settlements have relatively old populations. It is noteworthy that a few of the newly formed municipalities have very low values for this indicator, likely due to data imperfections. The greatest barrier we face to gaining a deeper understanding of the process of population ageing is a lack of time series on international migration, which in the case of Serbia mostly consists of out-migration.

These observations, when related to the prospective threshold, highlight some of the important features of population ageing in Serbia. It is important to point out that because of differences in population composition, municipalities can have the same share of people with a life expectancy of 15 years or less, but different prospective thresholds. However, municipalities with a large younger population and a lower prospective threshold are not the same as municipalities with a large older population and a high prospective threshold. When we look at population ageing through a prospective lens, we see that fertility is playing an important role in municipalities with Albanian ethnic majorities; that old-age mortality is defining population ageing in Vojvodina, and that the Southern and Eastern parts of Serbia are experiencing the consequences of rural migration.

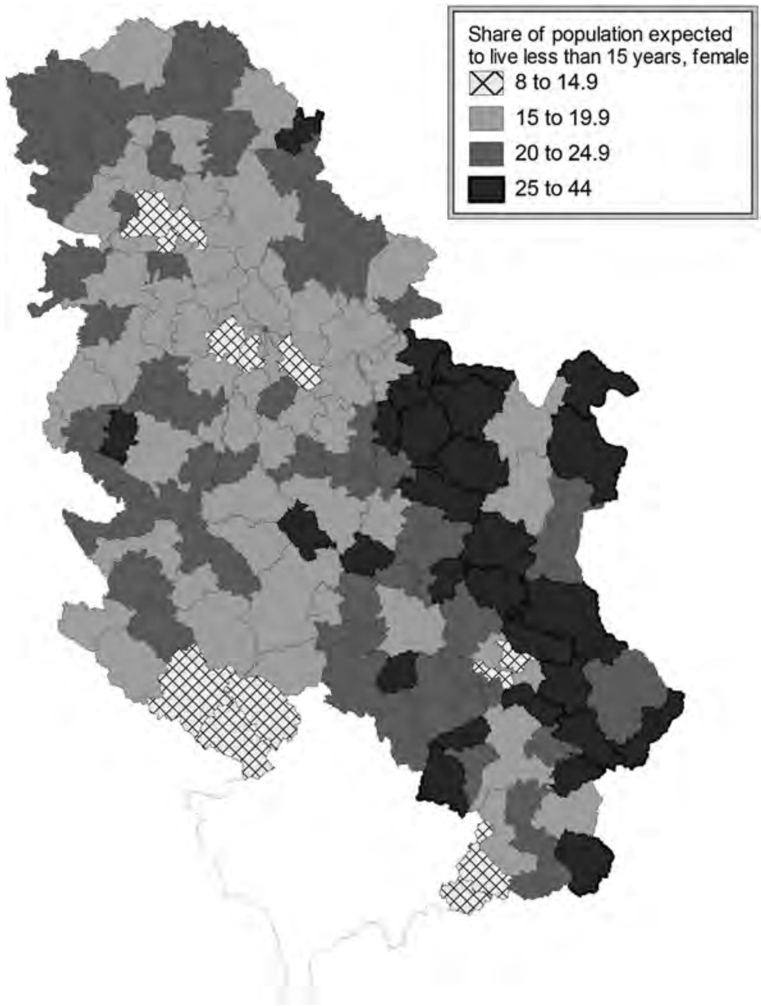
Similar observations can be made regarding the proportion of the female population with a remaining life expectancy of 15 years or less. In 2011, the

Map 3:
Proportion of the population with a remaining life expectancy of 15 years or less, male population, 2011



smallest shares of women with a life expectancy of 15 years or less were in the largest cities with numerous functions, and in municipalities with high fertility (and, consequently, a younger population structure). The greatest concentrations of women with a life expectancy of 15 years or less were again in Eastern and Western Serbia, but the number of municipalities in which the share of this population was more than 25% was higher for women than for men. It is interesting to note that in some municipalities this indicator was as high as 42% for men and 44% for

Map 4:
Proportion of the population with a remaining life expectancy of 15 years or less, female population, 2011



women, which means that in some municipalities close to the half of the total (male or female) population could expect to live less than 15 years. Such an unenviable reality clearly shows that the progressive trend of population ageing merits thorough examination, and that methodological advancements can shed some light from a different perspective.

5 Conclusion

Population ageing in Serbia is an unavoidable process of demographic change resulting from a long-term decrease in fertility and uneven improvements in mortality by age and sex over decades. The demographic developments in Serbia have also been affected by waves of migration, including by the emigration of guest workers to Western Europe in the 1960s, internal migration from rural areas to cities, the immigration of refugees, and brain drain in the 1990s. The survival of greater numbers of older people can be seen as a positive trend and a triumph of medical advancements, but if the share of older people is compared with the share of younger people, some unpleasant questions arise. New demographic methods, such as prospective and characteristics approaches that incorporate changes in the life expectancy of the older population, paint a more hopeful picture because they show that the health of older people has been improving in most developed countries. However, these new approaches may also reveal that in certain countries, including Serbia, life expectancy has been increasing more slowly than in most other developed countries. One of the most important properties of the prospective approach is that it can uncover some demographic relationships that traditional approaches miss or overlook. Further investigations of the uneven life expectancy values among the older population, and of the differentials in the prospective shares and prospective thresholds, will not only be useful research exercises, they will generate helpful input for population policy. These approaches can, for example, be used to address the question of whether health care and gerontology services for the older population should be redistributed, as there is a divergence between the concentrations of the (prospective) older population and the facilities that meet their needs.

Acknowledgements

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References

Devedzic, M. and J. Stojilkovic 2012. New concept of age(ing): Prospective age. *Stanovništvo* 50(1): 45–68.

Devedzic, M. and J. Stojilkovic Gnjatovic 2015. *Demographic profile of older population*. SORS: Belgrade.

IIASA, VID 2008. *European Demographic Datasheet 2008*. International Institute for Applied System Analysis, Vienna Institute for Demography.

IIASA, VID 2010. *European Demographic Datasheet 2010*. International Institute for Applied System Analysis, Vienna Institute for Demography.

IIASA, VID 2012. *European Demographic Datasheet 2012*. International Institute for Applied System Analysis, Vienna Institute for Demography.

IIASA, VID 2014. *European Demographic Datasheet 2014*. International Institute for Applied System Analysis, Vienna Institute for Demography.

Mamolo, M. and S. Scherbov 2009. Population Projections for Forty-Four European Countries: The Ongoing Population Ageing. *European Demographic Research Papers, 2* Vienna Institute of Demography of the Austrian Academy of Sciences, 1–63.

Sanderson, C. W. and S. Scherbov 2005. Average Remaining Lifetimes Can Increase as Human Populations Age. *Nature* 435(7043): 811–813.

Sanderson, C. W. and S. Scherbov 2007. A New Perspective on Population Aging. *Demographic Research* 16(article 2): 27–58.

Sanderson, C. W. and S. Scherbov 2008. Rethinking Age and Ageing. *Population Bulletin* 63(4).

Sanderson, C. W. and S. Scherbov 2010. Remeasuring Aging. *Science* 329(5997): 1287–1288.

Sanderson, C. W. and S. Scherbov 2014. The Characteristics Approach to the Measurement of Population Aging. Interim ReportIR-13-007, Laxenburg: IIASA.

The Statistical Office of Republic of Serbia 2012. Age and sex structure, Census publication. Belgrade: SORS.

Stojilkovic, J. 2010. Baby boom generation at the retirement onset. *Stanovništvo* 48(2): 75–91.

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The impact of physical health on the postponement of retirement

Michael Boissonneault and Joop de Beer*

Abstract

To mitigate the effects of population ageing, measures aimed at encouraging people to work longer are being implemented in many countries. However, older people are usually in poorer physical health, and poorer physical health is associated with premature labour force withdrawal. We investigate whether the age-related decline in physical health represents a hurdle to higher labour force participation levels at older ages by proposing a simulation in which the age profile of physical health stays constant over time, while all other factors that predict labour force participation are postponed. The model is fitted using data collected by the Survey of Health, Aging and Retirement in Europe (SHARE) in 14 European countries. The results show that on average across these countries, the effect of health on labour force participation levels is small. This effect is slightly bigger in countries in which labour force participation levels and the share of the population receiving disability benefits are already high. Thus, the decline in physical health with age should not greatly limit the effectiveness of policies designed to encourage employment at older ages.

1 Introduction

In the context of population ageing, measures are being taken in many OECD countries to promote work at older ages. One such measure is raising the pensionable age, or the age at which workers can start collecting pension benefits.

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Examples of countries that have increased the pensionable age include the United States, the Netherlands, the United Kingdom, Italy, and France (OECD, 2015).

Concerns have been raised about whether people will remain healthy enough to be able to continue to participate in the labour market as they grow older. The implicit assumption of linking changes in the pensionable age to changes in life expectancy is that the ability to work changes along with life expectancy. However, shifts in healthy life expectancy are arguably more closely related to changes in the ability to work than life expectancy as such. So far, the question of whether longer life is accompanied by more years in good health has not been fully answered. While the prevalence of severe disability seems to be declining over time, less severe forms of disability are becoming more common (Klijs et al. 2010; Lefrancois et al. 2013; Cambois et al. 2008). Trends in chronic conditions suggest that morbidity is expanding (Chatterij et al. 2015; Crimmins and Beltran-Sanchez 2011). Other measures of health have uncovered contradictory trends in different countries (Tsimbos and Verropoulou 2016).

People often retire before reaching pensionable age, and secure income via other governmental programmes. Retiring prior to reaching pensionable age is associated with poorer health. This association is weaker among people who collect early retirement benefits or unemployment benefits (Bazzoli 1985; Alavinia and Burdorf 2008; Robroek et al. 2013) but stronger among people who collect disability benefits (Boersch-Supan and Roth 2010; Karpansalo et al. 2004; Robroek et al. 2013). If healthy life expectancy stays constant over time and people do not become eligible for pension benefits until they reach a higher age, we can assume that more people will use these routes to early retirement. This dynamic could put more pressure on these programmes, thereby undermining the efficiency of a higher pensionable age. But how big is this problem likely to be?

In the present paper, we aim to quantify the potential impact on labour force participation levels if the health of the population fails to improve when the pensionable age is raised. We examine the European context, where important changes in retirement dispositions are to be expected. The contribution of our paper is twofold. First, we provide tools that help in conceptualising and modelling the link between changes in legislation around retirement, work, and health at older ages. Second, we provide evidence that sheds light on the debate about whether people will be healthy enough to be able to continue to participate in the labour force at older ages.

The paper is organised as follows. First, we provide a framework that establishes the conditions for higher participation in the context of a higher retirement age. Then, in the methods section, we give an overview of the data and variables used, we introduce the model, and we show how the simulation is performed. In the results section, we illustrate the fit of the model. Next, we present the results of the simulation for an average European country, first in the form of working life expectancy, then in the form of characteristics-based ages. In the last part of the results section, we test the sensitivity of the results by running the simulation on two groups of countries that differ concerning work and health at older ages. In the last section, we discuss the findings and the limitations of the study.

2 Framework

The increase in the age at which individuals become eligible to receive pension benefits is expected to have a positive effect on labour force participation levels at older ages. To our knowledge, however, it has never before been clearly stated how much labour force participation levels are expected to increase as a result of raising the normal retirement age. Furthermore, we know of no existing framework that has clarified through which mechanisms changes in the pensionable age will lead to higher labour market participation levels. In this section, we propose a framework that sheds light on these two issues.

Our framework builds on the characteristics approach to the measurement of population ageing developed by Sanderson and Scherbov (2013). The application of this approach has shown that the pace at which the average individual ages varies across different populations and subpopulations. Because chronological age is always computed the same way (i.e., using time from birth), it does not capture such differences. The characteristics that are relevant for defining how old a person is can be used alongside age to compare how people age across subpopulations. For example, a study conducted in the United States used the characteristics approach to compare the ageing rates of different subpopulations based on grip strength. The results showed that, on average, more educated people of a given chronological age had the same grip strength as less educated people with a younger chronological age. The authors therefore concluded that as measured by grip strength, more educated people age at a slower pace than less educated people (Sanderson and Scherbov 2014).

We consider here a hypothetical country with a normal retirement age of 65 years old. The characteristic "being eligible for pension benefits" is bound to age 65. Let us further assume that, in the same country, legislation is passed that postpones eligibility by two years of age. The individuals affected by the change in legislation will have the characteristics "being eligible for pension benefits" at the chronological age of 67 instead of 65. In both cases, however, the characteristics-based ages of these people are the same as measured by eligibility for pension benefits.

Eligibility for pension benefits does not always equate to retirement, as people often retire before or after that age. In the present paper, we are interested in people's behaviour as measured by their participation in the labour force. We will therefore concentrate on the characteristic "being out of the labour force because of retirement". We will assume that a change in legislation that postpones by *n* years the age at which an individual becomes eligible for pension benefits is intended to encourage an equivalent postponement of retirement. In other words, we assume a change of two years in the characteristic "being eligible for pension benefits" to mean an expected change of two years in the characteristic "being out of the labour force because of retirement", regardless of the age at which the change takes place.

Whether this expectation will materialise depends on the change in the schedule of all of the characteristics that together determine the timing of retirement. This set of characteristics includes, for example, the social norms regarding retirement and financial preparedness. The discrepancy between the expected change in retirement timing and the actual change will depend on two things: the size of the impact of each characteristic of the set on retirement timing; and the amount of change that takes place in this characteristic's schedule.

In the present paper, we investigate the specific impact of one of those characteristics; namely, physical health. Cross-sectional studies have consistently shown that there is an association between being in poor physical health and leaving the labour force before reaching the statutory retirement age. For example, conditions like stroke, diabetes, heart disease, and arthritis (Alavinia and Burdorf 2008; Smith et al. 2013; Kalwij and Vermeulen 2008); a lack of physical activity (Alavinia and Burdorf 2008); musculoskeletal problems (Alavinia and Burdorf 2008; Smith et al. 2013); and lower grip strength (Boersch-Supan and Roth 2010; Kalwij and Vermeulen 2008) are all factors associated with being out of the labour force prior to reaching the statutory retirement age. These associations hold when studied from a cross-sectional (Van Rijn et al. 2014) as well as from a longitudinal perspective (Van der Noordt et al. 2014).

Out of all of the characteristics that could hinder an increase in the labour market participation rates of older people, we consider the characteristic physical health to be of particular importance. While it may be possible to intervene to support some personal characteristics that pertain to the capacity of an older person to perform work, like motivation or skills; there is little that can be done to reverse a decline in physical health with age (Ilmarinen 2001). Furthermore, while changes in legislation may be able to influence characteristics like norms or financial preparedness, they have no or little impact on physical health.

Another important characteristic that influences work ability is mental health. The relationship between retirement and mental health is complex. While mental health has been found to have an impact on retirement (Olesen 2011), the opposite causality has also been found (Van der Heide 2013). Thus, age-related changes in mental health can be misleading (Riffe et al. 2015). By contrast, physical health can be more easily considered as a function of age, as there is no consistent evidence that retirement affects this dimension of health (Johnston and Lee 2009). For this reason, we focus on physical health, although the method used to measure physical must be chosen with care (Bound and Waidman 2007).

In the present paper, we propose a simulation in which we simulate a change in legislation that postpones eligibility for pension benefits by *n* years. We thereby assume that except for physical health, all of the characteristics that determine timing to retirement are also postponed. We then provide a measure of the discrepancy between the *expected n* value and the *actual n* value that originates from delaying the schedule of all characteristics that predict timing to retirement except physical health.

3 Methods

3.1 Data Source

We use data from wave 2 (2006–2007) of The Survey of Health, Ageing and Retirement in Europe (SHARE) (Börsch-Supan et al. 2008; Börsch-Supan et al. 2013; Börsch-Supan 2016)[1]. Although SHARE offers data at more points in time, wave 2 is the wave that best suits our needs in terms of measures of physical health. Furthermore, using data from this period allows us to avoid the negative impact that the Great Recession had on labour market participation at older ages in many countries. The countries that participated in wave 2 are Austria, Germany, Sweden, the Netherlands, Spain, Israel, Italy, France, Denmark, Greece, Switzerland, Belgium, the Czech Republic, Poland, and Ireland. We dropped observations collected in Israel to focus on Europe only. We further limit the observations we use to those in which the respondents were aged 50–64 at the time of the interview. The lower age limit is imposed by the survey. The upper age limit was chosen because the estimates become increasingly erratic at higher ages as the number of people who remain active in the labour market declines. The number of observations for those countries at these ages is 17,983. Figure 1 breaks them down by country.

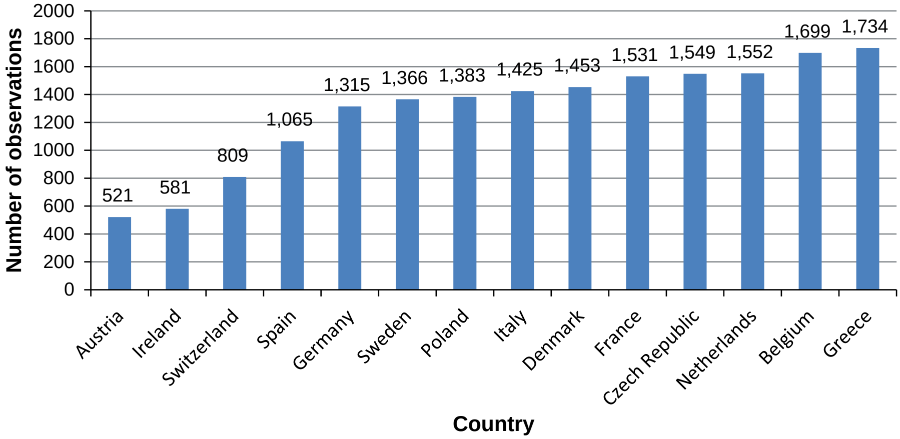
3.2 The variables

3.2.1 The health variable

The health variable is a composite measure in which we take the average of the standardised score obtained in three tests of physical health: grip strength, lung strength, and chair stand. Although SHARE offers more measures of health, we have chosen to limit ourselves to these three as they are the only measures available that are objective and measured on a continuous scale. The objective property allows us to avoid any justification bias (Lindeboom and Kerkhofs 2009), while

[1] The SHARE data collection has been primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812) and FP7 (SHARE-PREP: N°211909, SHARE-LEAP: N°227822, SHARE M4: N°261982). Additional funding from the German Ministry of Education and Research, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064), and from various national funding sources is gratefully acknowledged (see www.share-project.org).

Figure 1:
Number of observations included in the dataset, by country



the continuous property enables us to make a more precise assessment of the impact of health on labour force participation (more on this below). The three measures are all part of SHARE's module on objective measures of physical health. A fourth measure, walking speed, is not used here as it is only collected among people aged 75 and older.

Grip strength measures upper body strength, and is also an indicator of general physical vitality. It is assessed using a Smedley spring-type dynamometer, and is given in kilograms. Grip strength has been shown to predict incapacity, hospital stays, death, and decline in cognitive health. Good reviews of the literature on the link between grip strength and different health outcomes can be found in Bohannon (2008) and Sanderson and Scherbov (2014).

The lung test is performed using a *Mini-Wright Peak Flow Meter*. The meter measures the maximum strength with which the respondent expires air out of his or her lungs. The result is given in litres per minute. This test is especially useful in detecting respiratory problems such as asthma and emphysema. It can predict death (Cook et al. 1991) and the decline in cognitive capacities (Albert et al. 1995), and is linked to other measures of physical health (Seeman et al. 1994).

The chair stand test measures lower body strength, and is also an indicator of general physical vitality. Some variants of this test exist. We use the variant where the participant is asked to sit on a chair with his or her arms crossed and to get up and sit down again five times as quickly as possible. The result of the test is given in seconds. This test has been shown to predict mortality (Cooper 2010), and constitutes a good proxy of general health (Jones et al. 2000; Rozanska-Kirschke et al. 2006).

3.2.2 Labour force participation

The SHARE participants were asked about their labour force status at the moment of the interview. SHARE breaks down the answers into six categories: retired, working, unemployed, permanently disabled, homemaker, and other. We considered the people who were classified as working or unemployed to be active on the labour market, and assigned them the value one. Conversely, we considered the people who were classified as belonging to any of the other categories to be inactive, and assigned them the value zero.

3.2.3 Imputation

Some observations did not have a valid value for each variable of health or for the variable of labour force participation. Furthermore, the values that were less than three seconds for the chair rise were reconverted into missing, as we judged them to be very unlikely. This cut-off is based on another survey that contains results for the same test[2]. The numbers of missing values are as follows: 1183 observations concerning grip strength, 1773 observations concerning lung strength, 3379 observations concerning the chair stand, and 469 observations concerning labour force participation.

The missing values for health are mainly attributable to the respondent being unable to perform the necessary test, often because of a temporary or a long-lasting injury or disability. Accordingly, having a missing value is significantly associated with worse self-assessed health (regression models controlling for age and sex; coef: −.5400 (grip); −.4449 (peak); .6048 (chair); all significant at the 0.01 level). Ignoring those values would likely underestimate the impact of physical health on work.

We used multiple imputation in order to replace the missings with imputed values (Little and Rubin 2002). We performed a sequential imputation using a logistic regression on labour force status and a linear regression on grip strength, lung strength, and chair stand. The predictors were self-assessed health, country, gender, and age. The analyses were produced based on the average of 25 imputations. The command *mi impute* of the programme Stata version 12 was used to produce the imputation (Stata Corp 2011).

3.2.4 Standardization

Our analyses are based in part on the density function of the composite measure of physical health. We assume that each of the three measures of physical health are normally distributed. From the outset, the distributions of the grip and lung

[2] The English Longitudinal Survey on Ageing did not contain any value below three concerning this same measurement.

Table 1:
Summary statistics for the three measures of health, men

	Grip strength	Lung strength	Chair stand (log)
Mean	47.9	466.4	2.7
Median	48.0	470.0	2.7
Minimum	1.0	31.0	0.4
Maximum	84.0	880.0	3.9
Skewness	−0.3	−0.2	−0.9

Table 2:
Summary statistics for the three measures of health, women

	Grip strength	Lung strength	Chair stand (log)
Mean	29.4	319.7	2.6
Median	30.0	320.0	2.7
Minimum	0.0	32.0	0.5
Maximum	75.0	850.0	3.9
Skewness	0.0	−0.1	−1.0

strength outcomes were fairly close to a normal distribution for each sex. The chair stand outcomes were skewed to the right. We reconverted this measure's values into their natural logarithms. Tables 1 and 2 present some summary statistics on the distribution of each variable of health for men and women, respectively.

Since the value of each measure of health may not have the same meaning between the sexes and across countries, we reconverted each measure according to the standard deviation to which it belonged. The standard deviations were computed by sex and country. For each measure, we created 60 categories with a 0.1 standard deviation width going from three standard deviations below the median up to three standard deviations above the median. The values below and above those marks were considered to be extreme outliers, and the observations to which they belonged were dropped. The analyses were run on a total of 17,507 observations. As the results of the Pearson test displayed in Table 3 show, each measure of health is relatively independent of the other two. We therefore assume that the composite measure covers a fairly broad spectrum of physical health.

Table 3:
Correlation matrix between the measures of physical health grip strength, lung strength, and chair stand

	Grip strength	**Lung strength**
Grip Strength		
Lung Strength	0.2040	
Chair Stand	0.3438	0.2427

3.3 The model

The goal of the model is to isolate the specific influence of physical health from the other factors that influence retirement timing. This will allow us to simulate a postponement of all the characteristics that are relevant to retirement timing, except for physical health. The model rests on three building blocks: (1) participation as a function of age, (2) health as a function of age, and (3) participation as a function of health. The model is fully parameterised, which allows us to obtain more consistent estimates. Here we give a formal description of the model.

(1) *Participation as a function of age.* Age captures much of the variation in participation at older ages. It is a good proxy for different underlying factors that determine retirement timing, such as financial preparedness, norms, and health. We model change in labour force participation according to age following the logistic function

$$L_x = c_l + \frac{a_l e^{b_l(x-m_l)}}{1 + e^{b_l(x-m_l)}} \tag{1}$$

where L_x = the proportion of people participating in the labour market at age x, b determines the strength of the age-related change in participation, m is the age at which the slope is the steepest (i.e., the modal age of exits from the labour market), c is the lower boundary (i.e., the minimum proportion of people active) and $c + a$ is the upper boundary (i.e., the maximum proportion of people active). The subscript l refers to labour force participation. In estimating the parameters we imposed the constraint that c could not go below zero, as negative participation is impossible.

(2) *Health as a function of age.* The tendency for health to decline with age is the main reason why the ability of people to postpone retirement to higher ages has been questioned. The normally distributed variable of health is modelled based on its mean value and standard deviation. We modelled change in mean health according to age based on a logistic function, supposing that mean health varies between an upper and a lower boundary as we move along the x axis representing age

$$\mu_x = c_h + \frac{a_h e^{b_h(x-m_h)}}{1 + e^{b_h(x-m_h)}} \tag{2}$$

where μ_x = mean health at age x, b determines the strength of age-related changes in mean health, m is the age at which the slope is the steepest, c is the lower boundary (i.e., the minimum mean health) and $c + a$ is the upper boundary (i.e., the maximum mean health). The subscript h refers to health status.

We consider the health of the active population on the one hand, and the health of the whole population on the other. For each specification of the model, the health of the active population was found to be significantly better than the health of the non-active population (controlling for age and sex). Due to some random fluctuations, the curves of the age-specific mean values of physical health for the active population and for the whole population sometimes crossed. In order to obtain a realistic model, we impose two constraints. For both populations we set c at zero, based on the assumption that both curves approach zero as the age gets higher. We then impose the assumption that a is at least as high for the active population as for the whole population.

The health function of age is further defined in terms of the age-specific standard deviations. The variation in the observed standard deviations according to age do not show any significant slope. As there is also no theoretical reason to believe that the standard variation should vary according to age, we model the standard variation based on the average standard deviation observed between ages 50 and 64 for both sexes.

(3) *Participation as a function of health.* The variation in participation according to health is found based on the age-participation functions as well as on the age-health function described above. Based on the age-specific mean health and standard deviations, we find for each age the health density of the whole population. Using the same parameters, we find the health density of the active population, and we weight it according to the age-participation function described by Equation (1). The health-specific levels of participation are found by dividing the function describing the health of the active population weighted by the proportion participating in the labour market by the function describing the health of the whole population.

More formally, the health of the whole population is defined in terms of the density function

$$W_{h,x} = \frac{1}{\sigma_{w,x}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{h-\mu_{w,x}}{\sigma_{w,x}}\right)^2} \tag{3}$$

where $W_{h,x}$ = the share of the whole population with health status h at age x, $\mu_{w,x}$ is the mean health of the whole population at age x as provided by Equation (2), $\sigma_{w,x}$ is the standard deviation of the health measure of the whole population and h is a health value of infinitesimal width.

The health of the active population is defined in terms of the product of the age-specific level of participation and of the density function

$$A_{h,x} = L_x\left(\frac{1}{\sigma_a\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{h-\mu_{a,x}}{\sigma_a}\right)^2}\right) \tag{4}$$

where $A_{h,x}$ = the share of the active population with health status h at age x, L_x is the participation level at age x, $\mu_{a,x}$ is the mean health of the active population at age x as provided by Equation (2), $\sigma_{a,x}$ is the standard deviation of the health measure for the active population and h is a health value of infinitesimal width.

We divide the proportion of people who are active on the labour market inside of the density function of the active population by the density function one of the whole population. This provides us with health- and age-specific labour force participation rates

$$\frac{A_{h,x}}{W_{h,x}} = l_{h,x} \tag{5}$$

where $l_{h,x}$ = the level of participation at health h and age x.

3.4 The simulation

The simulation consists of applying the set of health-specific levels of participation described by Equation (5) to the population who are six years older. We base this figure on Eurostat's projections of increases in life expectancy at age 65 up to 2057 (Eurostat high variant scenario; Eurostat 2016b), as many countries have decided to synchronise their changes in the pensionable age with changes in life expectancy (OECD 2011).

The simulation can be described as a twostep procedure. First, the product of the postponed health-specific levels of participation and of the health density of the whole population is found

$$l_{h,x+n,t}W_{h,x,t} = A_{h,x,t+T} \tag{6}$$

where $A_{h,x,t+T}$ = the density for the population who are active in the labour market with health h and age x, supposing a postponement in all of the characteristics inherent to retirement timing except for physical health. Then, by summing up the values of A over all values of

$$h \sum_h A_{h,x,t+T} = l_{x+n,t+T} \tag{7}$$

we obtain a set of age-specific participation rates, where $l_{x+n,t+T}$ = the age-specific participation rate based on the assumption of a postponement of all of the factors that allow people to work longer, except physical health.

4 Results

The results are presented in three parts. First, we present the outcomes for men and women, pooling the data from all of the countries included in the dataset. We also demonstrate the fit of the model and illustrate how we simulated a postponement of retirement while keeping physical health constant. Second, using working life expectancy, we present for the same sets of observations the size of the impact of declining physical health on the postponement of retirement. Third, we assess the sensitivity of the results by comparing them between two groups of countries.

4.1 Fitting the model

Figure 2 presents for men and women the fitted and the observed values of labour force participation by year of age (Panel 1), mean health by year of age (Panel 2) and the standard deviation by year of age (Panel 3). The fitted values give the L, μ and σ, parameters, respectively.

The μ and σ values represented by the blue line (whole) in Panel 2 and in Panel 3 allow us to obtain health densities for the whole population for each year of age (Equation 3). The health density of men aged 55, $W_{x,55}$, is represented in blue in the top left graph of Figure 3. The μ and σ values represented by the red line (active) in Panels 2 and 3 of Figure 2 allow us to obtain health densities for the active population (Equation 4). These densities are multiplied by the proportion of people of the same age who are active on the labour market as described in Panel 1 of Figure 2. The resulting proportion is represented by the red bell-shaped surface in the top-left graph of Figure 3 ($A_{x,55}$).

Dividing the red bell-shaped surface with the blue bell-shaped line of the top-left graph of Figure 3 (Equation 5) provides us with the top-right graph in the same figure. The curve represents the health-specific participation rates ($l_{h,55}$).

The blue bell-shaped line in the bottom-left graph represents the health density of men aged 61. These men are assumed to have the same labour force participation levels as people aged 55 after postponement. However, the health of the 61-year-old men is worse than that of the 55-year-old men, as represented by the lower μ value (age 55 = 31.5; age 61 = 29.4). We multiply this health function by the health-specific participation levels of people aged 55 (Equation 6), as represented in the top-right graph ($l_{h,55}$). This provides us with the surface inside the bell curve represented in red; i.e., with the proportion of people working at age 61 supposing a six-year postponement of all of the factors that determine labour force participation except physical health (Equation 7). As a result of the limiting effect of declining physical health, the surface in red in the bottom-left graph is slightly smaller than the surface in red in the top-left graph.

Figure 4 illustrates the same process taking place between age 60 (baseline) and age 66 (postponement). Here we see that both the health and the participation levels decline with age. Figure 5 illustrate the resulting levels of participation for all years of age and compares them with the levels that would have been obtained if the decline in physical health had been postponed along with the rest of the characteristics that determine retirement timing.

Figure 2:
Estimated and observed values, proportion participating in the labour market, mean health, and standard deviation of health, men and women

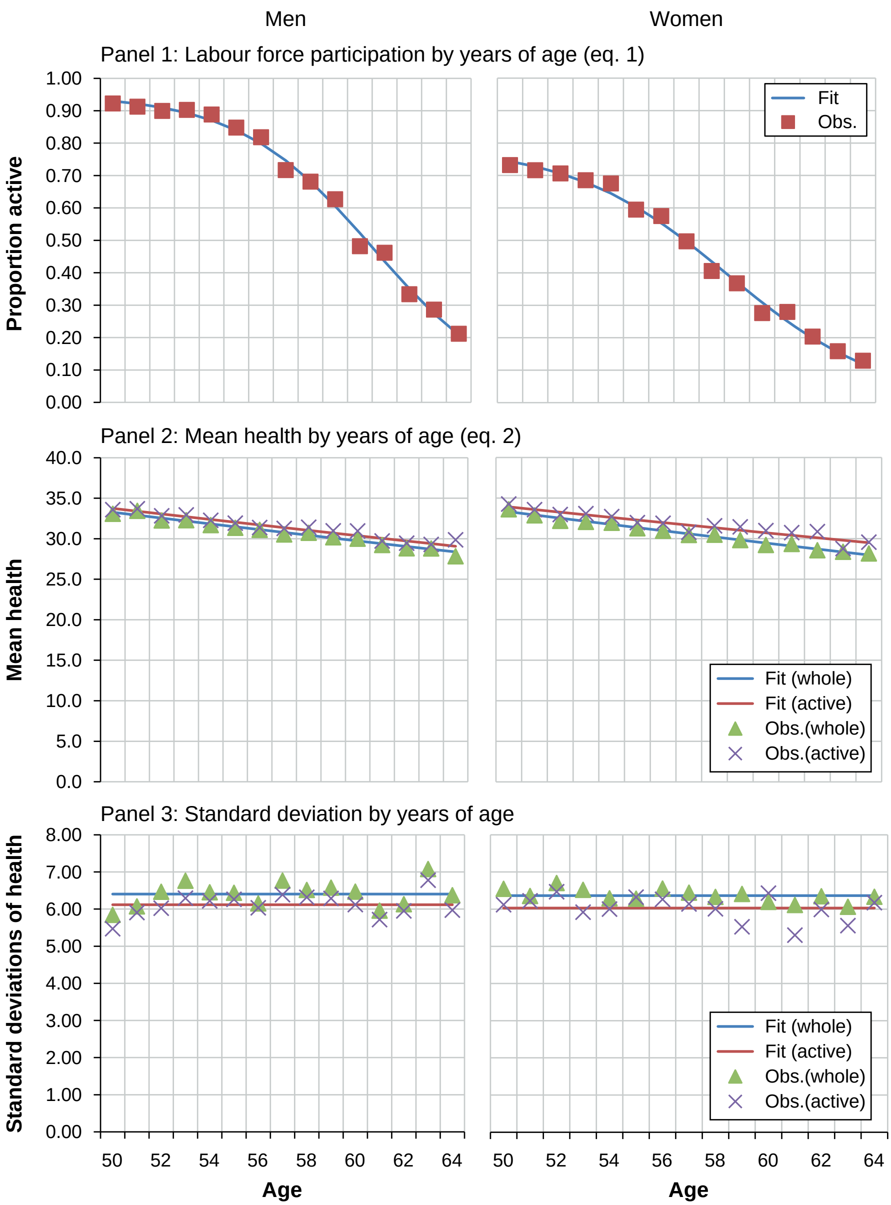


Figure 3:
Illustration of the simulation of a postponement of retirement keeping physical health constant, men, aged 55 to 61

Figure 4:
Illustration of the simulation of a postponement of retirement keeping physical health constant, men, aged 60 to 66

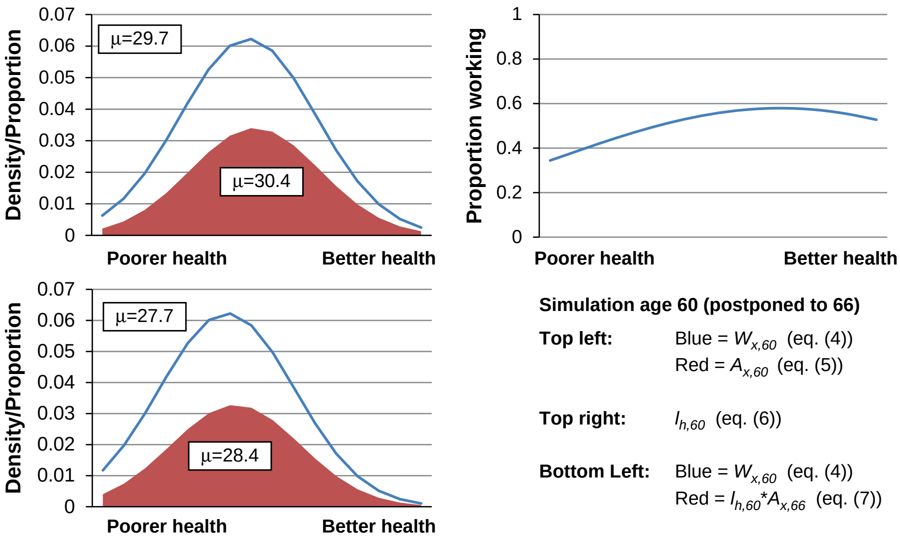
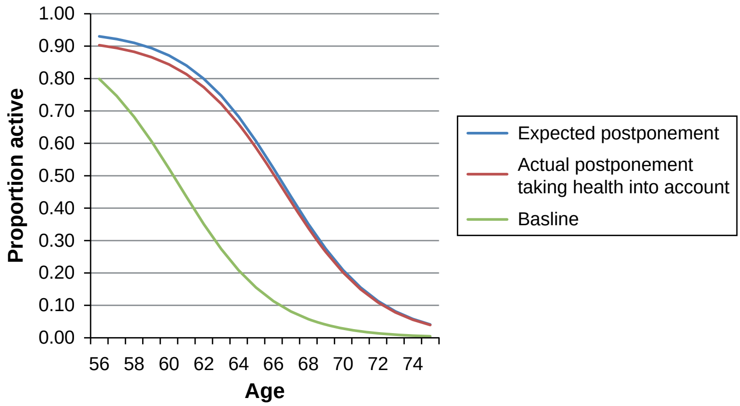


Figure 5:
Proportion active in the labour market by year of age, with and without the limiting effect of physical health on postponement



4.2 Working life expectancy

As a way to present the results, we computed abridged working life expectancy for each sex, pooling all observations from the 14 countries. The results represent the situation of an average European country. Here, the working life expectancy is just the area under the participation curve, as defined by Equation (7). It is calculated on 20 years of age, and conditionally on being active at baseline (i.e., the area under the curve is divided by participation at baseline).

The working life expectancy was first calculated between age 50 and age 70, without supposing any change in characteristics. The results of this computation are represented in Figure 6 by the full bars, which reach 10.74 years for men and 9.28 years for women. The postponement of the eligibility for retirement benefits, with a corresponding postponement in the whole set of characteristics inherent to retirement timing including physical health would mean that people aged 56–76 would, at baseline, have the same working life expectancy as people aged 50–70. The right part of the bars shows the discrepancy introduced by the failure to postpone the decline in physical health, while all of the other factors are postponed. The discrepancy is quite small in each case; reaching 0.36 years for men and 0.55 for women.

Another way to look at the same results is by using the characteristics-based age. Here, we use the remaining working life expectancy as a characteristic to assess the size of the discrepancy introduced by postponing all of the factors inherent in labour force participation except health. The results are presented in Table 4. Assuming a six-year postponement, people aged 56 are expected to have the same remaining working life expectancy as people aged 50 if all of the relevant factors are postponed.

Figure 6:
Working life expectancy ages 56–76, with and without the limiting effect of physical health on postponement, men and women

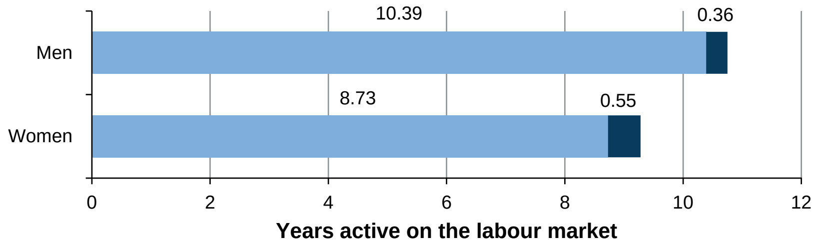


Table 4:
Age at which the working life expectancy is the same as the reference age, assuming a postponement of all of the factors except the decline in physical health, men and women

	Age at which the working life expectancy is the same as the reference age	
Reference age	**Men**	**Women**
56	55.62	55.42

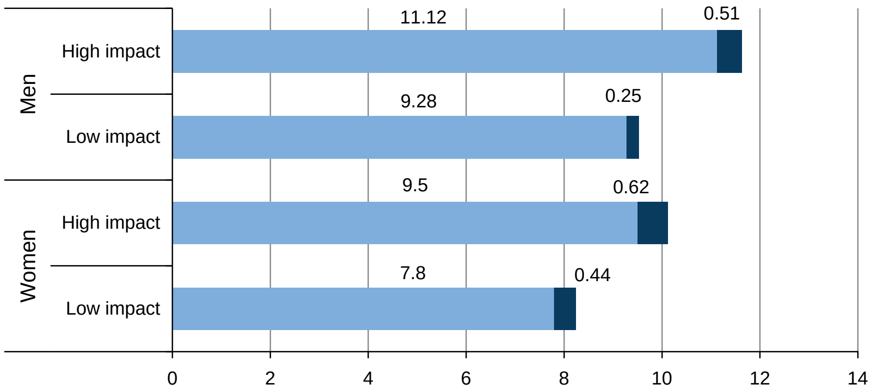
The failure to postpone the decline in physical health brings this figure down to 55.62 for men and to 55.42 for women.

4.3 Sensitivity analysis

The results presented above give us an idea of the impact of a constant age profile of physical health when the rest of the factors predicting retirement are postponed in an average European country. Here, we assess whether this average could hide big discrepancies between countries. In order to obtain more stable estimates, we produced results for two groups of countries rather than for single countries.

The groups are built so that they diverge from each other in terms of the impact of health on the postponement of retirement. The first group is comprised of countries that have higher levels of labour force participation at older ages and higher shares of the population aged 50–65 receiving disability benefits: namely, Sweden, Denmark, the Netherlands, Ireland, the Czech Republic, and Spain. The second group is comprised of countries that have lower levels of participation and lower shares of

Figure 7:
Working life expectancy ages 56–76, with and without the limiting effect of physical health on postponement, men and women, high vs. low impact countries



the population aged 50–65 receiving disability benefits: namely, France, Greece, Austria, Belgium, and Italy. Levels of participation at older ages are calculated by Eurostat for the year 2007 (Eurostat 2016a). The proportions of the population receiving disability benefits are calculated based on auto-declaration, and are found in Boersch-Supan (2010). The proportions of the population who are active at older ages and the proportions of the population receiving disability benefits are summarised in the appendix.

Our a priori assumption is that the impact of physical health on the postponement of retirement will be bigger in the first group, because the people in this group tend to still be working at higher ages, and older people tend to be in poorer physical health. Furthermore, we expect the higher share of the population receiving disability benefits to translate into a bigger impact of health on labour force participation. We call the first group the high-impact countries, and the second group the low-impact countries.

The results in Figure 7 confirm our expectation. In the high-impact countries, the number of years men are expected to spend in the labour market between ages 56 and 76 is 11.63. The actual figure is 11.12; a difference of 0.51 years. In the low-impact countries, men are expected to spend 9.48 years in the labour market between ages 56 and 76 with the postponement of all characteristics. When the limiting effect of physical health is taken into account, the figure is 9.28; a difference of 0.25 years.

The discrepancy between the high- and the low-impact countries is smaller among women. The number of years women are expected to spend in the labour market between ages 56 and 76 assuming a postponement is 10.13 in the high-impact countries. The actual value after taking the limiting effect of physical health into account is 9.50; a difference of 0.62 years. In the low-impact countries, working

Table 5:
Age at which the working life expectancy is the same as the reference age, supposing a postponement of all factors except physical health, men and women, high- vs. low-impact countries

	Age at which the working life expectancy is the same as the reference age			
Reference age	**Men high**	**Men low**	**Women high**	**Women low**
56	55.47	55.74	55.33	55.55

life expectancy is 8.24 years when the postponement of all factors is assumed. The actual figure is 7.80; a difference of 0.44 years.

The characteristic ages translate into the same results. In the high-impact countries, men aged 55.47 and women aged 55.33 have the same working life expectancy as their 50-year-old counterparts at baseline. In the low-impact countries, men aged 55.74 and women aged 55.55 have the same working life expectancy as their 50-year-old counterparts at baseline.

5 Discussion

In the present paper, we proposed a simulation of the impact of physical health on labour force participation when the age at retirement is postponed. The simulation was based on a framework in which we considered physical health as a distinct characteristic predicting retirement timing. In this framework, physical health was the only characteristic that was not postponed. The model – which is based on an age-function of labour force participation, as well as on changes in physical health according to age in the active population relative to the whole population – allowed us to isolate the effect of physical health on participation. Physical health was measured objectively using standardised grip strength, lung strength, and chair stand tests. The estimates were based on data collected in 2006 and 2007 in 14 SHARE countries.

The results suggest that physical health had a limited effect on the postponement of retirement. We saw that the link between labour force participation and physical health varied little between people aged 56–76 years and people aged 50–70. More precisely, when we included in our analysis a postponement of all of the characteristics that are relevant to retirement timing except physical health, we found that relative to the younger group, the older group had a working life expectancy that was only 0.36 years shorter among men, and 0.55 years shorter among women. In other words, a man aged 55.62 and a woman aged 55.42 could expect to work as many years as their 50-year-old counterparts if all of the characteristics that predict retirement except for physical health are postponed six years. The results did show some sensitivity to country differences. This was especially true among men, for whom the impact of stagnating physical health doubled between the so-called low- and high-impact countries. However, the impact in these countries remained small, as the loss in terms of working life expectancy due to physical health hovered at around 0.5 years out of almost 12 years.

We attribute our finding that stagnating health had only a small effect on the postponement of retirement to the following mechanism. Although physical health has an important effect on labour force participation – as has been repeatedly shown in occupational health research – this effect is strong for only a relatively small number of people. Furthermore, although physical health declines considerably with age, it does not deteriorate so quickly that older people are unable to continue working at higher ages, as long as the postponement of retirement stays within reasonable boundaries. Our observation that the impact of physical health was greater in the countries in which higher shares of the population were participating in the labour market and receiving disability benefits confirms those findings.

These results echo the findings of some previous studies that examined the question of whether older people are physically and mentally able to work longer. Crimmins et al. (1999) and Reynolds and Crimmins (2010) found that the self-assessed ability to work has been rising in the American population aged 50–70 since the end of the 1980s. Milligan and Wise (2015) found for a sample of OECD countries and Rehkopf et al. (2016) found for the United States that the unused capacity to work at older ages was "substantial". Milligan and Wise reached that conclusion based on levels of labour force participation specific to mortality conditions over time, while Rehkopf et al. did so based on estimates of the link between labour force participation and a battery of health and socio-demographic variables.

These results, as well as the findings presented in this paper, all strongly suggest that health should not be a serious hurdle to higher labour force participation at older ages. The present paper expands the existing evidence in several ways. First, we documented the specific role of physical health. Moreover, our use of objective measures allowed us to avoid the justification bias, which has been shown to have the potential to bias upwards the effect of health on labour force participation. The three measurements (grip strength, lung strength, and chair stand) cover a broad spectrum of physical health characteristics. The model, which rests on a few parameters that are easy to estimate, is fairly simple and can be reproduced with data from SHARE's sister studies, like the Health and Retirement Study and the English Longitudinal Studies on Ageing.

However, the approach we used here has some limitations. We did not consider the role of mental health, which has also been shown to also have an important impact on early exits from the labour force. If the physical demands of work continue to decrease, studying the impact of mental health on the ability to continue working could become more relevant. The three measures of physical health that we used were the only ones available that met our criteria. Even though these measures have been shown to be fairly independent of each other, they do not necessarily cover all aspects of physical health. As a result, the impact of physical health on labour force participation could turn out to be somewhat larger than is estimated here, although we do not believe that the findings of a study that covered a wider range of physical health characteristics would be dramatically different. Finally, we did not investigate how the impact of health varies according to socioeconomic status. Given that levels of health differ considerably across subpopulations, and that the work done by people with lower socioeconomic status is often physically demanding, this question constitutes an important topic for future research.

References

Alavinia, S. and A. Burdorf 2008. Unemployment and retirement and ill-health: a cross-sectional analysis across European countries. *International Archives of Occupational and Environmental Health* 82: 39–45.

Albert M. S., K. Jones, C. R. Savage, L. Berkman, T. Seeman, D. Blazer and D. W. Rowe 1995. Predictors of cognitive change in older persons: MacArthur studies of successful aging. *Psychol Aging* 10(4): 578–89.

Bazzoli, G. J. 1985. The Early Retirement Decision: New Empirical Evidence on the Influence of Health. *The Journal of Human Resources* 20(2): 214–234.

Bohannon, R. W. 2008. Hand-grip dynamometry predicts future outcomes in aging adults. *J Geriatr Phys Ther* 31: 3–10.

Börsch-Supan, A. and H. Roth 2010. Work disability and health over the life course. In *The individual and the welfare state: Life histories in Europe*. ed. Börsch-Supan, A. et al. Springer, Berlin. Forthcoming

Börsch-Supan, A. 2016. Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 2. Release version: 5.0.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w2.500

Börsch-Supan, A., A. Brugiavini, H. Jürges, A. Kapteyn, J. Mackenbach, J. Siegrist and G. Weber 2008. *First results from the Survey of Health, Ageing and Retirement in Europe (2004–2007). Starting the longitudinal dimension*. Mannheim: Mannheim Research Institute for the Economics of Aging (MEA).

Börsch-Supan, A., M. Brandt, C. Hunkler, T. Kneip, J. Korbmacher, F. Malter, B. Schaan, S. Stuck, and S. Zuber 2013. Data Resource Profile: The Survey of Health, Ageing and Retirement in Europe (SHARE). *International Journal of Epidemiology*, DOI: 10.1093/ije/dyt088.

Bound, J. and T. Waidman 2007. Estimating the Health Effects of Retirement. University of Michigan Retirement Research Center. Working paper WP 2007-168, 36 p.

Cambois, E., A. Clavel, I. Romieu and J.-M. Robine 2008. Trends in disability-free life expectancy at age 65 in France: consistent and diverging patterns according to the underlying disability measure. *European Journal Ageing* 5: 287–298.

Chatterij, S., J. Byles, D. Cutler, T. Seeman and E. Verdes 2015. Health, functioning, and disability in older adults—present status and future implications. *The lancet* 385(9967): 563–575, 7–13 February 2015.

Cook, N. R., D. A. Evans, P. A. Scherr, F. E. Speizer, J. O. Taylor and C. H. Hennekens 1991. Peak expiratory flow rate and 5-year mortality in an elderly population. *American Journal of Epidemiology* 133(8): 784–794.

Cooper, R. 2010. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ* 341: c4467.

Crimmins, E. M. and H. Beltran-Sanchez 2011. Mortality and morbidity trends: Is there compression of morbidity? *The Journal of Gerontology Series B: Psychological Sciences and Social Sciences* 66(1): 75–86.

Crimmins, E., S. L. Reynolds and Y. Saito 1999. Trends in health and work ability among the older working-age population. *Journal of Gerontology: Social Sciences* 54B(1).

Eurostat 2016a. Active population by age, sex and nationality. Eurostat database. http://ec.europa.eu/eurostat/data/database. Consulted on 22 November 2016.

Eurostat 2016b. Population projections. http://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-projections-data. Consulted on 22 November 2016.

Ilmarinen, J. E. 2001. Aging workers. *Journal of Occupational and Environmental Medicine* 58: 546 doi:10.1136/oem.58.8.546 E.

Jones C. J., Rikli R. E. and W. C. Beam 2000. A 30-s chair-stand test to measure lower body strength in community-residing older adults. *J of Aging & Physical Activity* 8: 85.

Johnston, D. W. and W. S. Lee 2009. Retiring to the good life? The short-term effects of retirement on health. *Economic Letters* 103: 8–11.

Kalwij, A. and F. Vermeulen 2008. Health and labour force participation of older people in Europe: What do objective health indicators add to the analysis? *Health Economics* 17(5): 619–638.

Karpansalo, M., P. Manninen, J. Kauhanen, T. A. Lakka and J. T. Salonen 2004. Perceived health as a predictor of early retirement. *Scandinavian Journal of Work, Environment and Health* 30(4): 287–292.

Klijs B., J. P. Mackenbach and A. E. Kunst 2010. Disability occurrence and proximity to death. *Disability and Rehabilitation* 32(21): 1733–1741.

Little, R. and D. B. Rubin 2002. *Statistical analysis with missing data*, second edition. Wiley

Lefrancois, G., S. Vezina, J. Keefe and J. Legare 2013. Trends and characteristics affecting disability amon older Canadians living in private households. *Canadian Studies in Populations* 40: 3–4.

Lindeboom, M. and M. Kerkhofs 2009. Health and work of the elderly: Subjective health measures, reporting errors and endogeneity in the relationship between health and work. *Journal of Applied Econometrics* 24: 1024–1046.

Milligan, K. and D. A. Wise 2015. Health and work at older ages: using mortality to assess the capacity to work across countries. *Population Ageing* 8: 27–50.

OECD 2011. "Linking Pensions to Life Expectancy", in Pensions at a Glance 2011: Retirement-income Systems in OECD and G20 Countries. OECD Publishing.

OECD 2015. *Pensions at a Glance 2015: OECD and G20 indicators*. OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/pension_glance-2015-en.

Olesen, S. C., P. Butterworth and B. Rodgers 2012. *Social Psychiatry Psychiatric Epidemiology* 47: 735. doi:10.1007/s00127-011-0375-7.

Rehkopf, D. H., N. E. Adler and J. W. Rowe 2016. The impact of health and education on future labour force participation among individuals aged 55–74 in the United States of America: the MacArthur Foundation Research Network on an Aging Society, *Ageing and Society*, *First View*, published online: 11 April 2016.

Reynolds, S. L. and E. M. Crimmins 2010. Trends in the work ability among men and women in the older American population: 1997–2007. *Eur J Ageing* 7(4): 249–256. doi: 10.1007/s10433-010- 0166-0.

Riffe, T., P. H. Chung, J. Spijker and J. MacInnes 2015. Time-to-death patterns in markers of age and dependency. MPIDR working paper WP 2015-003. July 2015.

Robroek S. J. W., M. Schuring, S. Croezen, M. Stattin and A. Burdorf 2013. Poor health, unhealthy behaviors, and unfavorable work characteristics influence pathways of exit from paid employment among older workers in Europe: a four year follow-up study. *Scand J Work Environ Health* 39(2): 125–133. doi:10.5271/sjweh.3319.

Różańska-Kirschke, A., P. Kocur, M. Wilk and P. Dylewicz 2006. The Fullerton Fitness Test as an index of fitness in the elderly. *Medical Rehabilitation* 10(2): 9–16.

Sanderson, W. C. and S. Scherbov 2013. The characteristics approach to the measurement of population aging. *Population and Development Review* 39: 673–685.

Sanderson, W. C. and S. Scherbov 2014. Measuring the speed of aging across population subgroups. *PLoS ONE* 9(5): e96289. doi:10.1371/journal.pone.0096289.

Seeman, T. E., P. A. Charpentier, L. F. Berkman, M. E. Tinetti, J. M. Guralnik, M. Albert, D. Blazer and J. W. Rowe 1994. Predicting changes in physical performance in a high-functioning elderly cohort: MacArthur studies of successful aging. *J Gerontol.* 49(3): M97–M108.

Smith, P., C. Chen, C. Mustard, A. Bielecky and D. Beaton 2013. Examining the relationship between chronic conditions, multi-morbidity and labour market participation in Canada: 2000–2005. *Ageing and Society* Available on CJO 2013 doi:10.1017/S0144686X13000457.

StataCorp. 2011. *Stata Statistical Software: Release 12*. College Station, TX: StataCorp LP.

Van der Heide, I., R. M. Van Rijn, S. J. W. Robroek, A. Burdorf and K. I. Proper 2013. Is retirement good for your health? A systematic review of longitudinal studies. *BMC Public Health* 13: 1180.

Van der Noordt M., H. IJzelenberg, M. Droomers, et al. 2014. Health effects of employment: a systematic review of prospective studies *Occup Environ Med* 71: 730–736.

Van Rijn, R. M., S. J. W. Robroek, S. Brouwer and A. Burdorf 2014. Influence of poor health on exit from paid employment: a systematic review. *Occupational and Environmental Medicine* 71: 295–301.

Verropoulou, G. and C. Tsimbos 2016. Trends in disability in Europe using various indicators and SHARE data. Presented at the European Population Conference.

Appendix

Figure A.1:
Percentage of the population aged 50–64 active on the labour market, by country

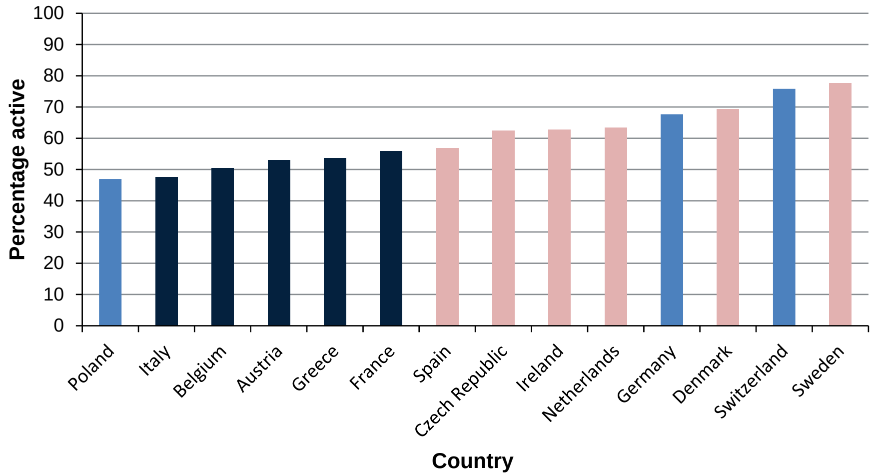
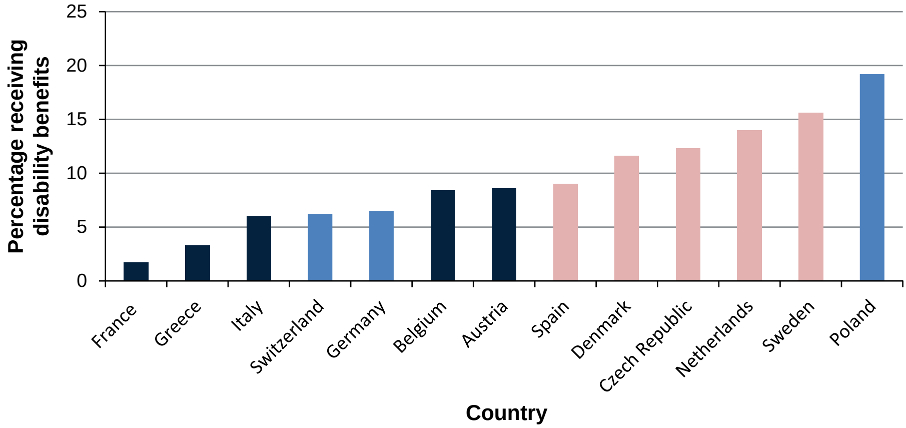


Figure A.2:
Percentage of the population aged 50–64 receiving disability benefits, by country



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Adjusting prospective old-age thresholds by health status: empirical findings and implications. A case study of Italy

*Elena Demuru and Viviana Egidi**

Abstract

While traditional measures of population ageing are bound to the concept of chronological age, new indicators have been proposed that take into account the dramatic changes that have occurred in later life due to increasing longevity. In this paper, we re-evaluate demographic ageing in Italy using prospective old-age thresholds based on both total remaining life expectancy and remaining life expectancy in good health. We show that the proportion of individuals above the prospective thresholds has been increasing much more slowly than the proportion of people aged 65 years and older, and that the increase in the proportion of individuals above the prospective thresholds adjusted for health status has been more or less large depending on trends in health status at older ages. Given these results and the ongoing improvements in health conditions among older people, we think the consequences of population ageing for Italian society could be less severe than expected.

1 Introduction

It is well known that all developed countries have been experiencing a marked decline in mortality driven by medical progress and improving living conditions over the whole life cycle (Amick et al. 2002; Ben-Shlomo and Kuh 2002; Demakakos et al. 2015), and especially in early life (Kermack et al. 2001;

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Bengtsson et al. 2009; Beltràn-Sanchez et al. 2013). While the expansion of knowledge in the early 20th century about the treatment and the prevention of infectious and acute diseases led to important reductions in mortality at younger ages, death rates at adult and older ages did not start to decrease significantly until further scientific advancements in the treatment of chronic diseases were made after World War II (Meslé and Vallin, 2000; Caselli 2015). Since then, mortality has been continuously decreasing, especially at older ages (Kannisto 1994, 1996; Rau et al. 2008). People are now surviving to increasingly old ages, and it is no longer uncommon for individuals to live 100 years or more (Jeune and Kannisto 1997; Robine and Vaupel, 2002; Vaupel 2010).

As a result of mortality decline, the average life span has steadily lengthened over time, reaching very high levels in recent years. Thus, life expectancy at birth doubled in most developed countries during the 20th century (Human Mortality Database, 2015). Nonetheless, life expectancy is expected to continue to grow in the near future, and the most optimistic scholars even believe that a maximum human life expectancy does not exist (Caselli and Vallin, 2001; Oeppen and Vaupel, 2002). During the 1950s, life expectancy at older ages also began to increase. Thus, just as life expectancy at birth has been extended to ages once considered unreachable, the number of remaining years to live of people who have reached older ages has risen to such an extent that it is now usual (in the literature, as in life) to distinguish between the "old" and the "oldest-old"; with the latter group consisting of individuals aged 80 or 85 years and older (Suzman et al. 1992; Baltes and Smith 1999; Vaupel 2010).

As extending life must be considered one of humankind's greatest achievements, nobody who was present at the start of this process could have imagined that such a positive development in population dynamics would cause growing concern over time. Nonetheless, a potentially negative consequence of rising life expectancy is that, together with a simultaneous drop in fertility rates, this longevity revolution (Butler, 2008) is leading to a dramatic ageing of the populations of many countries, profoundly changing the balance between their young, adult, and older components (Cohen 2005). The problem is that many questions about the impact of this shift in the age structure of a population towards older ages on the sustainability of a country's health – as well as on its social and economic systems – still remain unanswered.

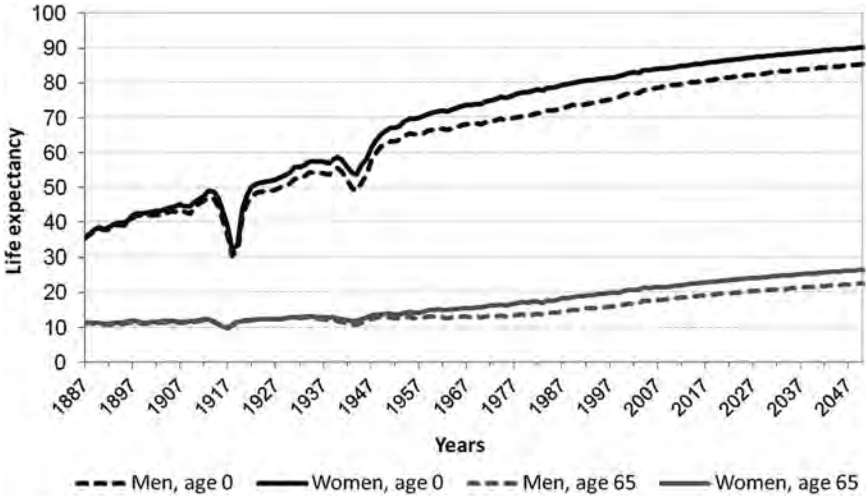
Pessimistic assumptions regarding our future ability to deal with the (potentially negative) effects of population ageing currently prevail; thus, the idea that it will gradually become impossible to satisfy the needs of the elderly for health and social care is widespread. These assumptions are, however, often based on observed trends in the numbers and the proportions of individuals who survive beyond a fixed age threshold – usually 65 years old. Such measures of population ageing do not take into account the possibility that many characteristics of the population at a given age could change over time. Yet some of these characteristics – in addition to life expectancy – are already changing; indeed, because people are living longer, the whole life course is being stretched. This expansion of the life course is modifying the meaning of particular ages, as well as the timing of transitions from one life course stage to another (Lee and Goldstein 2003). People who are aged 65 years today can expect to enjoy longer and healthier lives than ever before. On average, they are more educated and live in better social and economic conditions than their peers born 50 to 100 years before. Even from a biological point of view, many studies have demonstrated that, although ageing is a universal process, a significant degree of plasticity exists both between individuals and between successive cohorts. This finding appears to hold regardless of the measure of biological ageing that is adopted (McDonald, 2014). For instance, the frailty index – i.e., the proportion of deficits present in an individual out of the total number of age-related health variables considered – depends on gender, education, marital status, and other socio-demographic characteristics; and thus changes from one cohort to another (Jones et al. 2005). The allostatic load – i.e., an indicator of individual ageing that links physiologic dysregulation to the risk of adverse health outcomes (Crimmins et al. 2003) – increases rapidly until age 65, and then stabilises, partially due to a selection effect among older people with respect to physiological status. It has indeed been demonstrated that biological risk and physiological dysregulation are strongly related to socioeconomic conditions over the life cycle, and that people in less favourable conditions die at younger ages. Thus, the physiological status differences between individuals are reduced at older ages (Crimmins et al. 2009). Finally, research on telomere length – which is frequently used as a biomarker of ageing – confirms that the rate of progression of individual ageing is strongly influenced by lifestyle. This explains the progress observed over time, and provides support for the claim that ageing can be further slowed through active health policies (Shammas 2012). It is thus clear that the ageing process has been changing at the individual level, and that we should rethink our assumptions about the relationship between age and different phases of life (Holstein and Gubrium 2000; Lee and Goldstein 2003). These developments should also be taken into account when evaluating the magnitude and the impact of ageing at the population level. New concepts and indicators are needed to correctly identify the individuals who should be truly classified as elderly, as being older than a fixed threshold is no longer a satisfactory measure of who is or is not "old". Studies on the economic impact of widespread longevity have also shown that forecasting future trends in health care expenditures based on the numbers and the proportions of people above the conventional old-age threshold (i.e., 65 years) would lead to unjustifiably alarming forecasts. Indeed, the bulk of health care expenditures are related to services administered to individuals during their last years of life (regardless of their chronological age); and to external factors, such as the cost of new technologies (Stearns and Norton 2004; Seshamany and Gray 2004; Shang and Goldman 2008).

Different indicators may be used to represent the dramatic increase in longevity that occurred during the second half of the 20th century. The modal age at death is one of these indicators, and is an appropriate metric to use to describe increases in survival to very high ages (Kannisto 2000, 2001; Robine et al. 2007), as it is particularly sensitive to mortality dynamics at older ages (Horiuchi et al. 2013). Many studies have tried to link trends in the risk of death at older ages to the process of ageing (Horiuchi and Wilmoth 1997; Barbi 2003; Vaupel 2010; Salinari and De Santis 2014; Zheng 2014). Other researchers have proposed new measures of population ageing based on remaining life expectancy. The most promising of these proposed measures introduces the concept of prospective age (Sanderson and Scherbov 2007, 2008, 2010, 2015; Lutz et al. 2008), thereby reactivating a line of pioneering research that was much discussed in the 1970s (Ryder 1975). Referring to prospective age instead of chronological age allows us to account for improvements in longevity. Prospective age is the age at which the number of years of remaining life expectancy equals the number of years observed at an age taken as a point of reference, such as a specific age in a past time period. We will use this concept to identify old-age thresholds that can be compared both between different years and between men and women, using the same value of remaining life expectancy as a point of reference.

While the prospective age concept can itself be seen as a breakthrough in the research into possible alternatives to traditional measures of population ageing, we think that this indicator could be further enhanced by incorporating information on the population's health status that accounts for the quality of the extra years of life gained through longevity improvements. The good news is that in countries where high-quality data on population health are available, prospective ages adjusted for health status can be easily computed by referring to remaining health expectancies – i.e., to the number of remaining years of good health – instead of the total remaining life expectancy.

In this paper, we apply the concept of prospective age (both with and without adjusting for health status) to an analysis of the past, present, and future magnitudes of population ageing in Italy. Our aim is to re-estimate population ageing using prospective measures that take into account not only increased longevity, but also the associated changes in the health conditions of older individuals in the population. In order to do so, we calculate the total number of prospective old-age thresholds between 1887 and 2050 (observed up to 2013 and then projected), and the prospective old-age thresholds without functional limitations and in good self-rated health for 1991, 1994, 2000, 2005, and 2013; i.e., for those years for which data from the national health interview survey conducted by the Italian National Institute of Statistics (Istat) are available. We show that the total prospective old-age thresholds have been rising steadily over the whole period, and that the increases in the shares of men and women above these thresholds have been much smaller than the increases in the shares of men and women aged 65 and older. After adjusting for health status, these results are even more encouraging, but they also confirm the existence of large gender differences. Indeed, the positive evidence that the old-age thresholds without functional limitations and in good self-rated health rose even more than the total prospective thresholds should be weighed against our finding that women made less progress than men, as women generally reported being in worse health (the well-known health-survival gender paradox, Oksuzyan et al. 2008), and the health status of women does not appear to be improving as rapidly as that of men.

Figure 1:
Observed and expected life expectancy of Italian men and women aged zero and 65 years between 1887 and 2050



Source: The observed data come from the Human Mortality Database for the years 1887–2013, and the predicted data come from Istat for the years 2014–2050.

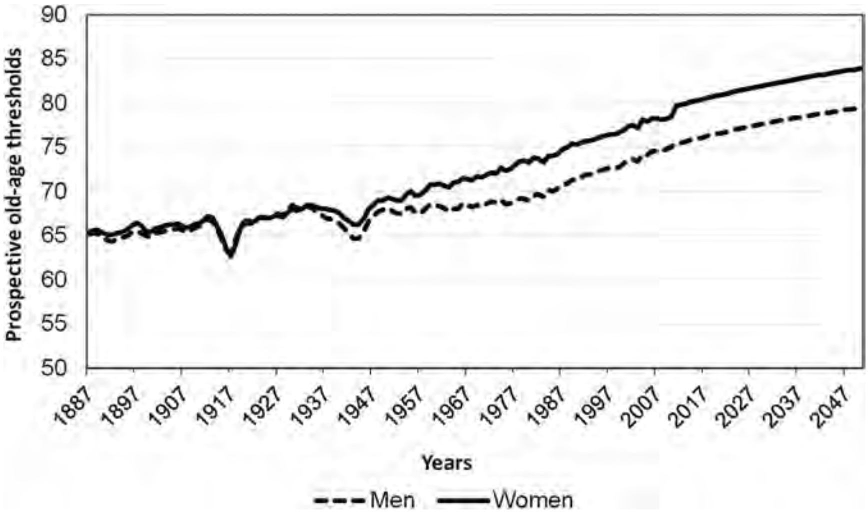
2 How old is the Italian population? Traditional VS new measures of ageing

As in other developed countries, Italy has been experiencing a notable increase in life expectancy; a trend that is expected to continue into the foreseeable future. To better illustrate the evolution of life expectancy over time, the historical and the projected trends in life expectancy in Italy – at birth and at age 65 – are shown in Figure 1.

Between 1887 and 2013, life expectancy rose from about 36 years to 79.8 years among men and to 84.6 years among women. Furthermore, over the same period the remaining life expectancy at age 65 virtually doubled: it rose from approximately 10 years in 1887 to 18.3 years among men and to 21.8 years among women in 2013. Most of these improvements have, however, occurred over the last 60 years: in 1950, life expectancy at age 65 was 13.0 years among men and 13.9 years among women.

Apart from observing the rapid pace of these improvements, it is interesting to note that a significant gender gap in survival conditions has been gradually emerging. Whereas at the end of the 19th century Italian men and women had roughly the same life expectancy, today women can expect to live 4.8 years longer than men at all ages (down from a maximum gap of 6.7 years in 1980). According to forecasts made by Istat, by 2050 life expectancy will reach 85 years for men and 90 years for women;

Figure 2:
Prospective old-age thresholds, defined as the age at which the remaining life expectancy equals that of a person aged 65 living in 1887, for men and women between 1887 and 2050



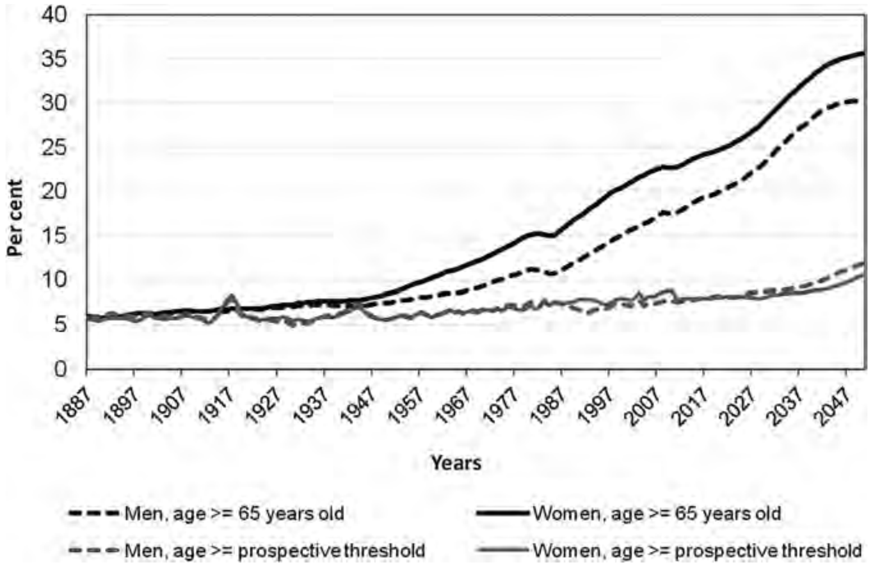
Source: Our calculations based on observed data from the Human Mortality Database for the years 1887–2013, and predicted data by Istat for the years 2014–2050.

thus, Italians are expected to gain another five years of life between 2013 and 2050. In addition, life expectancy at age 65 is projected to reach 22 years for men and 26.5 years for women by 2050; or four years more than in 2013.

The effects of such a dramatic increase in life expectancy are visible in the form of rising numbers and proportions in the population of individuals older than age 60 or age 65. However, the pace of this trend differs considerably depending on which measure of demographic ageing is used. If, as is generally the case today, we assume that age 65 is the old-age threshold, then we find that the proportion of elderly people in the Italian population has been growing at such a rapid pace that there may be doubts about society's ability to deal with the consequences. If, however, we use a prospective rather than a retrospective old-age threshold, a much less alarming demographic picture appears, as we show with the following example.

Based on the method suggested by Sanderson and Scherbov (2007), we first define the prospective old-age threshold for each year between 1887 and 2050 as the age at which the remaining life expectancy equals the remaining life expectancy observed at age 65 in the first year of the considered period; i.e., 1887. We then define as elderly those individuals who are older than the threshold. As can be seen in Figure 2, this measurement strategy allows us to compute a dynamic threshold that constantly changes to include any evidence of survival improvements at higher

Figure 3:
The proportion of individuals aged 65 and older and the proportion of individuals older than the prospective old-age thresholds, defined for each year as the age at which the remaining life expectancy equals that of a person aged 65 living in 1887, for men and women between 1887 and 2050



Source: Our calculations based on observed data from the Human Mortality Database for the years 1887–2013, and predicted data by Istat for the years 2014–2050.

ages. A significant increase in the threshold is indeed observed, especially since the beginning of the second half of the last century. Applying this strategy, we estimate that in 2013 the prospective old-age threshold was 76.5 for men and 80 for women, and will be 79.4 for men and 83.8 for women in 2050 (i.e., between 1887 and 2050, this threshold is expected to increase by 14 years for men and by 19 years for women). Yet in this scenario as well, we see that a gender gap has been gradually emerging over time.

In Figure 3, we can see the differences in the estimates of population ageing generated by the analysis based on the chronological old-age threshold (fixed at age 65), and by the analysis based on the new and dynamic prospective old-age threshold, which refers to remaining life expectancy.

The share of individuals older than the fixed threshold of 65 years increased from 6% of both men and women in 1887 to 18.3% of men and 23.3% of women in 2013. On the other hand, the share of individuals older than the prospective thresholds went from 6% to almost 8% of both men and women; a very limited increase relative to the increase observed when using traditional measures of ageing (2% among both men and women vs. 12% among men and 17% among women). Over the next 50 years, the share of individuals in the population older than the prospective thresholds is expected to grow more consistently, but still at a much slower pace than the proportion of the population aged 65 years and older. While 35% of women and 30% of men are expected to be in the second group in 2050, just 12% of men and 11% of women are expected to be in the first group in 2050. It is important to note that the gender differences are much smaller when we analyse population ageing using the prospective rather than the chronological definition of the old-age threshold.

3 Changing health conditions among the elderly in Italy

A criticism that could be made about the use of the prospective measure of ageing is that it tracks progress in survival, without evaluating the conditions in which older people live their extra years of life. The prospective old-age thresholds defined in the previous paragraph do not include any information about the quality of the remaining life expectancy. This could lead to inaccurate estimates of the socioeconomic consequences of population ageing, as improved longevity would be a truly positive development if the years of life gained are spent in good health. Thus, the negative effects of ageing on socioeconomic sustainability might be overestimated if people are indeed living longer and healthier lives, as healthy agers could continue to have a role in society (Vaupel 2006), and would place a much smaller burden on the health system than is currently anticipated. Conversely, rising longevity could simply result in an increase in the number of years spent in poor health, and, consequently, in the proportion of individuals with high social and health care needs. In other words, individuals who survive to older ages could be a burden or a resource, depending on their health status. Based on this reasoning, we think that prospective old-age thresholds should account for changes in the health conditions of the elderly in order to provide more realistic information about the potential impact of population ageing in a specific country.

Here, we present a brief overview of the health status of the Italian elderly population. These results will be used in the next paragraph to adjust the prospective old-age thresholds for health status. Istat has been conducting nationally representative health interview surveys approximately every five years since 1991. Thus, high-quality, comparable health data are available for Italy for a period of about 20 years. We calculated health expectancies – i.e., the number of years of life to be lived in good health (Jagger and Robine 2011; Jagger et al. 2014) – of individuals aged 65, 70, and 75 in 1991, 1994, 2000, 2005, and 2013. We computed two different health expectancies: functional health expectancy, which refers to the number of years to be lived without severe functional limitations; and subjective health expectancy, which refers to the number of years to be lived in good self-rated health. Four different areas of functional limitation are included in the definition of functional health: limitations of the senses, limitations of movement, limitations in activities of daily living (ADL), and confinement. Self-rated health is assessed for

Table 1:
Total life expectancy (LE), functional limitation-free life expectancy (LFLE), life expectancy with functional limitations (LLE) and proportion of years to be lived without functional limitations (HR) among men and women of age 65, 70 and 75 in the years 1994, 2000, 2005 and 2013

	Men					Women				
	1991	**1994**	**2000**	**2005**	**2013**	**1991**	**1994**	**2000**	**2005**	**2013**
65 years										
LE	15.2	15.5	16.5	17.5	18.6	19.0	19.4	20.4	21.3	22.0
LFLE	12.1	12.7	13.7	14.6	15.6	13.8	14.1	14.9	15.6	16.1
LLE	3.0	2.8	2.8	2.8	2.9	5.1	5.2	5.4	5.6	5.9
*HR (*100)*	*80.1*	*81.9*	*83.1*	*83.7*	*84.2*	*72.9*	*73.0*	*73.3*	*73.5*	*73.3*
70 years										
LE	12.0	12.3	13.0	13.7	14.7	15.0	15.3	16.2	17.1	17.7
LFLE	9.0	9.5	10.3	10.9	11.8	10.0	10.3	10.9	11.5	11.9
LLE	3.0	2.8	2.8	2.9	2.9	5.0	5.1	5.3	5.5	5.8
*HR (*100)*	*75.2*	*77.2*	*78.8*	*79.2*	*80.2*	*66.7*	*66.9*	*67.3*	*67.5*	*67.3*
75 years										
LE	9.1	9.3	10.0	10.5	11.3	11.3	11.6	12.4	13.1	13.7
LFLE	6.1	6.6	7.2	7.6	8.3	6.6	6.8	7.3	7.7	8.1
LLE	3.0	2.8	2.7	2.9	2.9	4.7	4.8	5.1	5.4	5.6
*HR (*100)*	*67.4*	*70.5*	*72.5*	*72.4*	*74.2*	*58.5*	*58.5*	*59.0*	*59.1*	*59.2*

Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1994, 2000, 2005, and 2013.

each individual using the question: “How is your health in general?”. Respondents who answered “good” or “very good” are described as being in good health. It should be noted, however, that because this question had a different formulation in the 1991 Italian national health interview survey, it is not possible to compare the results obtained for this year with the other results. This shortens the observed interval from 1994 to 2013.

For all of the considered ages and calendar years, Table 1 reports the total life expectancy, the life expectancy free of functional limitations, the life expectancy with functional limitations, and the proportion of years to be lived without functional limitations relative to the total remaining life expectancy (*health ratio*). When we look at the table, we see immediately that the number of years to be lived without functional limitations has been rising continuously since 1991, at all ages and for both genders. At the same time, however, the increase in this figure has been much more pronounced among men than among women. In addition, over the past two decades, the number of years spent with functional limitations – which was already higher among women than among men in 1991 – increased slightly among women,

Table 2:
Total life expectancy (LE), life expectancy in good self-rated health (HLE), life expectancy in poor self-rated health (PHLE) and proportion of years to be lived in good self-rated health (HR) among men and women of age 65, 70 and 75 in the years 1994, 2000, 2005 and 2013

	Men				Women			
	1994	**2000**	**2005**	**2013**	**1994**	**2000**	**2005**	**2013**
65 years								
LE	15.5	16.5	17.5	18.6	19.4	20.4	21.3	22.0
HLE	11.0	12.3	14.4	15.5	12.9	14.8	15.9	16.6
PHLE	4.5	4.3	3.0	3.1	6.5	5.6	5.3	5.4
*HR (*100)*	*71.0*	*74.1*	*82.7*	*83.5*	*66.7*	*72.6*	*74.9*	*75.6*
70 years								
LE	12.3	13.0	13.7	14.7	15.3	16.2	17.1	17.7
HLE	8.1	9.1	10.9	11.9	9.9	11.2	12.2	12.8
PHLE	4.2	3.9	2.8	2.8	5.5	5.0	4.8	4.9
*HR (*100)*	*66.2*	*70.2*	*79.6*	*81.0*	*64.4*	*69.0*	*71.8*	*72.3*
75 years								
LE	9.3	10.0	10.5	11.3	11.6	12.4	13.1	13.7
HLE	5.7	6.6	8.0	8.8	7.2	8.1	8.9	9.4
PHLE	3.6	3.3	2.5	2.5	4.4	4.3	4.2	4.3
*HR (*100)*	*61.2*	*66.4*	*76.0*	*77.8*	*61.8*	*65.6*	*68.2*	*68.6*

Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1994, 2000, 2005, and 2013.

but remained largely stable among men. Thus, the gender gap in health expectancy has been widening over the years, with men gaining more years of healthy life than women. This pattern is clearly demonstrated by the health ratio, which is not just higher among men than among women, but is also rising at a faster pace among men than among women. In 1991, 65-year-old men were expected to live 80.1% of their remaining life without functional limitations, compared to 72.9% for women. By 2013, the corresponding values had risen to 84.2% and 73.3%. Moreover, these gender differences tend to increase with age, especially in the most recent years: in 2013, 75-year-old women could expect to live only 59.2% of their remaining life without functional limitations, a much lower proportion than the 74.2% observed among men. Overall, Table 1 describes a relative compression of morbidity scenario, as it has been defined by Fries (1989): i.e., for both men and women, the number of years spent without functional limitations increased more than the number of years spent with functional limitations (Robine and Mathers 1993; Doblhammer and Kytir 2001).

Table 2 refers to self-rated health, and shows the healthy life expectancy (i.e., the life expectancy in good health), the life expectancy in poor health, the total life expectancy, and the health ratio for all ages and years starting from 1994. These indicators paint an even more favourable picture, as they show that since 1994, both men and women have experienced not only increases in the number of years lived in good health, but significant decreases in the number of years lived in poor health. Moreover, the health ratio for functional limitations has increased especially sharply. Notable gender differences are, however, still evident: women were already disadvantaged at the beginning of the study period, and especially at older ages, women did not make as much progress as men during the subsequent years. For instance, among 65-year-olds in 1994, the average share of life to be lived in good health was 71% for men and 66.7% for women; whereas among 65-year-olds in 2013, the corresponding proportions were 83.5% and 75.6%. Yet despite these differences, the trends described for both men and women show an absolute compression of the morbidity scenario, as the years spent in poor health decreased in both absolute and relative terms.

In sum, the health of the Italian older population has been evolving positively in recent decades, as major health problems are shifted towards older ages, and high-quality years are added to the total lifespan. Health has been improving among men in particular, while improvements seem to have been slowing down over time among women.

4 Prospective old-age thresholds: an adjustment for health status

To take into account the health conditions of older people in Italy, we substitute the functional limitation-free and healthy life expectancies for the total life expectancy in the calculation of prospective ages. Using this approach, we are able to define old-age thresholds based not only on progress made in survival, but on changes in the health-related quality of life.

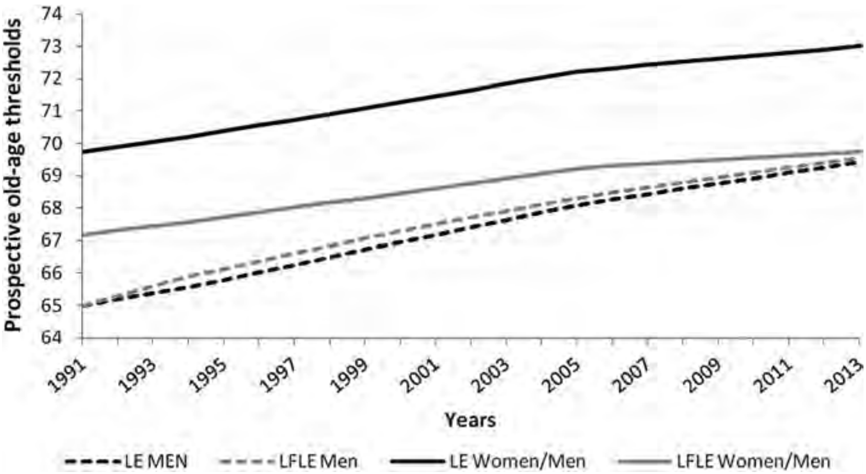
Focusing on the functional dimension of health, we compute the prospective old-age threshold without functional limitations as the age at which the functional limitation-free life expectancy equals that observed for an individual aged 65 in 1991, i.e., the first year of the reference period; we then compare this threshold with the total prospective ages (all health states considered), which is calculated by referring to the same year (Table 3). Among men, the functional limitation-free old-age threshold in 2013 was 69.6 years and the total prospective old-age threshold was 69.4 years; i.e., 4.6 and 4.4 years more than in 1991. Among women, the functional limitation-free old-age threshold in 2013 was 67.8 and the total prospective old-age threshold was 68.6 years; i.e., 2.8 and 3.6 years more than in 1991. Therefore, both prospective thresholds increased for both men and women over the last two decades. However, a difference emerges: the functional limitation-free prospective old-age

Table 3:
Total (LE) and functional limitation-free (LFLE) prospective old-age thresholds, respectively, defined as the ages at which the total and the functional limitation-free life expectancies equal those observed at age 65 in 1991 for men and women, and the prospective old-age thresholds of women relative to those of men in the years 1991, 1994, 2000, 2005, and 2013

Prospective	Men					Women					Women/Men				
age	1991	1994	2000	2005	2013	1991	1994	2000	2005	2013	1991	1994	2000	2005	2013
LE	65.0	65.6	67.0	68.1	69.4	65.0	65.5	66.7	67.8	68.6	69.7	70.2	71.3	72.2	73.0
LFLE	65.0	65.9	67.3	68.3	69.6	65.0	65.4	66.4	67.2	67.8	67.2	67.6	68.5	69.2	69.7

Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1991, 1994, 2000, 2005, and 2013.

Figure 4:
Total (LE) and functional limitation-free (LFLE) prospective old-age thresholds, respectively, defined as the ages at which the total and the functional limitation-free life expectancies equal those observed at age 65 in 1991 for men, and the corresponding prospective old-age thresholds of women relative to those of men between 1991 and 2013



Note: The prospective old-age thresholds are calculated for 1991, 1994, 2000, 2005, and 2013; and were obtained by interpolation for all other years.
Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1991, 1994, 2000, 2005, and 2013.

threshold increased slightly more than the total prospective old-age threshold among men, and less than the total threshold among women. Thus, in contrast to estimates of survival probabilities, these indicators suggest that elderly women have been doing much worse than their male counterparts, and that men have been ageing more successfully than women.

However, direct comparisons between men and women using the prospective old-age thresholds reported in Table 3 can be misleading, as men and women may be expected to live different numbers of years at the starting reference point, both in total and without functional limitations. Therefore, the remaining life expectancy used as a reference for computing the prospective age is not the same for men and women. To create comparable indicators, we calculated a gender-comparative prospective old-age threshold for women as the age at which the total and the health-specific remaining life expectancies equal those observed among men at age 65 in 1991. We called this new measure “the prospective comparative old-age threshold of women in respect to men”.

The results, shown in Figure 4, confirm that including information on health has a large impact on prospective old-age thresholds. When we consider the total

Table 4:
Total (LE) and healthy (HLE) prospective old-age thresholds, respectively, defined as the age at which the total and the healthy life expectancies equal those observed at age 65 in 1994 for men and women, and the prospective old-age thresholds of women relative to those of men in the years 1994, 2000, 2005, and 2013

Prospective	Men				Women				Women/Men			
age	1994	2000	2005	2013	1994	2000	2005	2013	1994	2000	2005	2013
LE	65.0	66.4	67.6	69.1	65.0	66.2	67.3	68.1	69.7	70.8	71.8	72.6
HLE	65.0	68.3	69.9	71.6	65.0	67.6	69.1	69.9	68.1	70.2	71.6	72.3

Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1994, 2000, 2005, and 2013.

prospective old-age thresholds, we see that a wide gender gap emerges, and that this gap has decreased only slightly over the period. These thresholds were indeed 4.7 and 3.6 years higher for women than for men in 1991 and 2013, respectively. The picture painted by the functional limitation-free prospective old-age thresholds is rather different. While it still appears that women aged later than men, the difference between the comparative prospective thresholds of the two sexes was much smaller. Moreover, because the gender gap had been decreasing so much over time, it was almost no longer visible by 2013: whereas the old-age threshold was two years higher among women than among men in 1991, the difference was just 0.1 years in 2013.

The results obtained for the subjective dimension of health are somewhat different. In this case, the prospective old-age thresholds in good self-rated health are defined as the ages at which the remaining healthy life expectancy equals that observed at age 65 in 1994. As Table 4 shows, in recent decades these thresholds increased more than the total prospective ages among both men and women. This result was expected given the more balanced distribution of improvements in self-rated health between older men and women. More specifically, the healthy prospective old-age threshold increased 6.6 years among men but just 4.9 years among women, while the total prospective old-age thresholds increased 4.1 years among men and 3.1 years among women.

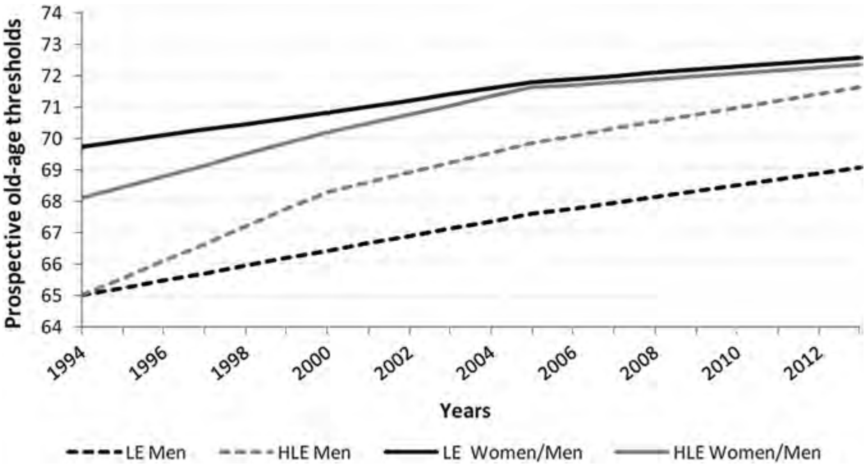
In addition, for the healthy prospective measures, we calculated gender-comparative thresholds in order to be able to make appropriate comparisons between men and women (see Figure 5). As in the case of functional limitations, we see a wide gender gap when we look at the total prospective ages, but a much narrower gender gap when we look at the prospective old-age threshold in good health: i.e., the gender differences for these two indicators were 4.7 and 3.1 years in 1991, and were 3.5 and 0.7 years in 2013. Once again, the gender differential observed at the beginning of the period has almost disappeared over time.

5 Ageing or rejuvenating? A re-evaluation of the impact of population ageing in Italy

We are now able to assess the impact of using prospective measures, both with and without correction for the health-related quality of life expectancy, when estimating population ageing. The results in Tables 5 and 6 are presented separately for each dimension of health because prospective old-age thresholds have different reference years, and, consequently, different remaining life expectancies that are assumed to be constant in time.

We first focus on the results obtained for functional health (Table 5). As has already been shown in Figure 3, the proportion of people over age 65 in the Italian population has been growing steadily since the 1950s. The rate of increase in this share has never slowed down, and is even expected to speed up in the near future,

Figure 5:
Total (LE) and healthy (HLE) prospective old-age thresholds, respectively, defined as the age at which the total and the healthy life expectancies equal those observed at age 65 in 1994 for men, and the corresponding prospective old-age thresholds of women relative to those of men between 1994 and 2013



Note: The prospective old-age thresholds are calculated for 1994, 2000, 2005, 2013 and obtained by interpolation for all other years.
Source: Our calculations based on data from the Italian national health interview survey conducted by Istat in the years 1994, 2000, 2005, and 2013.

fuelled by large generations of “baby boomers” progressing into later life. Yet if we change our perspective, we see that the percentage of individuals above the total prospective old-age threshold – calculated without adjusting for the health conditions at higher ages – is always substantially lower than the proportion of people aged 65 and older among both men and women. Furthermore, the growth in this percentage over the whole period has been limited: only 13.8% of men and 14.8% of women were above the total prospective thresholds in 2013. When correcting prospective ages to include only the years expected to be lived free of functional limitations, the situation changes only slightly for men, but worsens significantly for women: the proportion of women above the threshold rose from 15% in 1991 to 18.3% in 2013.

Some comments can be made about these results. First, a very discouraging picture emerges when traditional measures of population ageing are applied. Second, using prospective measures without taking into account the quality of the years of life gained with improving longevity – as is usually done in the literature – leads to an underestimation of ageing among women. This happens because the total prospective age does not take into account the increase in the number of years to be lived with functional limitations among women.

Table 5:
The proportion of individuals aged 65 years and older, the proportion of individuals above the total gender-comparative prospective old-age threshold, and the proportion of individuals above the gender-comparative prospective old-age threshold without functional limitations in the Italian male and female populations for the years 1991, 1994, 2000, 2005, and 2013

	% ≥ 65 years of age		% ≥ total gender-comparative prospective old-age threshold		% ≥ prospective gender-comparative old-age threshold without functional limitations	
Years	**Men**	**Women**	**Men**	**Women/Men**	**Men**	**Women/Men**
1991	12.6	17.5	12.6	12.2	12.6	15.0
1994	13.5	19.0	12.8	12.8	12.5	15.7
2000	15.3	20.8	13.2	13.7	12.9	16.8
2005	16.6	22.1	13.2	14.1	13.0	17.3
2013	18.6	23.6	13.8	14.8	13.6	18.3

Note: The references for the prospective ages are the total and the functional limitation-free remaining life expectancies of a man aged 65 in 1991.
Source: Our calculations based on population data from Istat.

Table 6:
The proportion of individuals aged 65 years and older, the proportion of individuals above the total gender-comparative prospective old-age threshold, and the proportion of individuals above the gender-comparative prospective old-age threshold without functional limitations in the Italian male and female populations for the years 1994, 2000, 2005, and 2013

	% ≥ 65 years of age		% ≥ total gender-comparative prospective old-age threshold		% ≥ prospective gender-comparative old-age threshold in good health	
Years	**Men**	**Women**	**Men**	**Women/Men**	**Men**	**Women/Men**
1994	13.5	19.0	13.5	13.4	13.5	15.1
2000	15.3	20.8	13.8	14.2	11.9	14.9
2005	16.6	22.1	13.7	14.5	11.4	14.7
2013	18.6	23.6	14.4	15.4	11.7	15.6

Note: The references for the prospective ages are the total and the healthy remaining life expectancies of a man aged 65 in 1994.

Source: Our calculations based on population data from Istat.

The results obtained when considering the subjective dimension of health and the year 1994 as a reference for calculating prospective ages are even more interesting (Table 6). The proportion of individuals above the total prospective old-age threshold rose among women, increasing from 13.4% to 15.4% between 1994 and 2013. However, the corresponding proportion among men fluctuated over the same period, between a minimum of 13.5% and a maximum of 14.4%. After adjusting the prospective thresholds for the perceived health status, it appears that from 1994 to 2005 the proportion of elderly individuals was declining. This was mainly the case among men, as the proportion of men above the old-age threshold in good health dropped from 13.5% to 11.4%; women experienced a smaller decrease, as the corresponding proportion of women declined from 15.1% to 14.7%. These figures tell us that, assuming an old-age threshold adjusted for perceived health, the Italian population was rejuvenating rather than ageing up to 2005. Even though the share of people older than the prospective threshold in good health subsequently rose, the picture created by the prospective measures of ageing is profoundly different from the one we are used to seeing. Finally, the proportion of men above the prospective old-age threshold adjusted for self-rated health was generally lower than the share of men above the total prospective threshold; whereas the situation among women did not change much.

It should be noted that, on the one hand, without adjusting for self-perceived health, the proportion of men above the prospective old-age threshold was higher than that of women; but that on the other, completely different trends appear for men and women when adjusting for self-perceived health. Using the total prospective ages in this case means overlooking the evidence that the number of years expected to be lived in poor health has been declining over time, and that this number has been falling faster among men than among women. Generally, it appears that using total prospective ages rather than prospective measures adjusted for self-rated health could lead to more pessimistic estimates of population ageing, as the first indicator could be disregarding possible improvements in the quality of life at older ages.

In sum, we assert that the impact of population ageing could be profoundly re-evaluated if prospective measures were commonly accepted. Such measures could prove especially useful when attempting to quantify the magnitude of population ageing in those countries in which the longevity of people aged 65+ has improved the most. Moreover, it appears that prospective old-age thresholds should be corrected by including indicators of the quality of life expectancy, as the failure to include such indicators could lead to the under- or the overestimation of population ageing when health worsens or improves over time.

6 Discussion and conclusions

In association with decreasing fertility, rising longevity has led to a dramatic increase in the proportion of elderly people in the population in recent decades. The elderly have traditionally been defined as individuals older than a fixed chronological age threshold (usually 60 or 65). The growth in the older population can be seen as an extraordinarily positive development resulting from sharp declines in human mortality over the past century. However, as the share of older people in the population has expanded, concerns about the ability of society to adapt to this completely new age structure have been raised. Population ageing is indeed an epochal change that poses many challenges, and that requires a deep reorganisation of social, economic, and welfare systems in all affected countries (Christensen et al. 2009; Börsch-Supan et al. 2005; Soede et al. 2004).

At an individual level, increasing longevity has stretched the whole life course (Lee and Goldstein 2003): childhood and adulthood have lengthened considerably over the years, and adolescence and the so-called "fourth age" have even emerged as new stages of life (Higgs and Gilleard 2015; Perls 2015). Young-old people, and especially the baby boomers born after World War II, spent most or all of their lives in conditions of unprecedented prosperity and of expanding educational opportunities. Thus, these generations have different psychophysical profiles, behaviours, and expectations than previous cohorts (Baltes and Smith 2003; Crimmins 2004; Fuller-Iglesias and Smith 2009; Rice et al. 2010; Sabbath et al. 2015; Pinheiro Melo Borges Tiago 2016; Hülür et al. 2016).

Despite these changes, the definition of old age most commonly used to measure population ageing has not evolved over time, and is now obsolete. The concept of old age should be broader than the simple crossing of a fixed age threshold that does not refer to an individual's life history, health, and vitality (Ryder, 1975; Legaré and Desjardins, 1987; Egidi, 1992; Sanderson and Scherbov, 2007). Health conditions are especially relevant when assessing the impact of population ageing on society: indeed, the true borderline between adult and older ages could be drawn at the point at which a person's health status deteriorates to the extent that he/she is no longer able to live successfully and independently, and has thus become an economic and social burden on society (Preston and Wang, 2006; Caselli and Egidi, 2011). A healthy ageing process is essential for successful ageing, as remaining healthy allows older people to continue to be active participants in society.

Our analysis of the most recent evolution of population ageing in Italy takes into account advancements in both survival and health at older ages, and confirms the need to adjust prospective measures of ageing by considering the quality of the extra years of life gained. In particular, our results show that the estimates of the share of people above the prospective old-age threshold in the Italian population can be distorted if no reference to individual health status is included. Indeed, when using total prospective thresholds, the impact of population ageing could be either underestimated or overestimated depending on how specific health dimensions have evolved in conjunction with increasing longevity. When assessing population ageing among women, using total prospective old-age thresholds can lead to unduly optimistic estimates, whereas applying prospective old-age thresholds adjusted for functional limitations can generate more realistic estimates. Meanwhile, when assessing population ageing among men, using total prospective old-age thresholds can lead to more pessimistic estimates than using prospective old-age thresholds adjusted for self-rated health. It is, in any case, clear that traditional measures based on fixed thresholds greatly overestimate the levels of population ageing and the pace of its increase, and thus arouse undue levels of concern. These measures completely fail to recognise that people older than a certain chronological old-age threshold can still be healthy and dynamic enough to face other challenges in life.

Our results are extremely encouraging, as they show that health in later stages of life has improved among Italians over the last two decades, with positive consequences for the magnitude of population ageing. In particular, the trends in health conditions we observed among the elderly are consistent with the most optimistic hypothesis regarding the possible evolution of health in old age: i.e., the hypothesis of the compression of morbidity (relative or absolute, depending on the health dimension considered) into a shorter period of time before death (Fries, 1980). At the same time, however, our results raise concerns about two specific problems. First, it seems that women are finding it more difficult than men to improve their health status, and are thus often unable to take full advantage of their longer lives. Second, improvements in health conditions at older ages, and especially in self-rated health, have been slowing in the most recent years; i.e., between 2005 and 2013. This slowdown may reflect the impact of the 2008 economic crisis on the health of the Italian population. Other negative effects could become visible in the future: 11% of survey respondents in 2013 reported that they had given up at least one health care service, even if they needed it (Istat, 2013). If Italians cut back on their use of preventive and other health care services, improvements in the health status of the population could decline further in the coming years.

To conclude, the most important result of our analysis is that if the evolution of population health is positive enough, and a measure of population ageing able to take into account longevity and health improvement is used, we may observe a rejuvenation of the population. Italian men have indeed been ageing in relatively good health over the past two decades, and when we look at the old-age thresholds adjusted for self-perceived health, we see that the male population was rejuvenating until the mid-2000s. Nevertheless, the two negative pieces of evidence discussed above should not be ignored, but should instead be seen as a warning that we cannot rely on the natural course of events. A range of actions aimed at supporting positive trends are needed. For example, improvements in health education could help to promote healthier behaviours throughout the lifespan, as together with working and living conditions, health-related behaviours at young and adult ages are predictive of health in later life (Börsch-Supan et al. 2011). Action should also be taken by citizens at the individual and societal levels, and by governments at a policy level to advance two main goals: challenging the stereotype that elderly people are a burden on society by emphasising the potential contributions they can make as the population ages (Blum et al. 2015; Higgs and Gilleard 2015); and promoting healthy ageing as the only means of assuring the future sustainability of our health, social, and economic systems.

References

Amick, B. C., P. McDonough, H. Chang, W. H. Rogers, C. F. Piper and G. Dungan 2002. Relationship between all-cause mortality and cumulative working life course psychosocial and physical exposures in the United States labor market from 1968 to 1992. *Psychosomatic Medicine* 64: 370–381.

Baltes, P. B. and J. Smith 1999. Multilevel and systemic analyses of old age: Theoretical and empirical evidence for a fourth age. In *Handbook of theories of aging*, ed. V. L. Bengtson and K. W. Schaie, 153–173. New York: Springer.

Baltes, P. B. and J. Smith 2003. New frontiers in the future of aging: from successful aging of the young old to the dilemmas of the forth age. *Gerontology* 49: 123–135.

Barbi, E. 2003. *Assessing the Rate of Ageing of the Human Population*. MPIDR Working Paper WP 2003-008.

Beltrán-Sánchez, H., M. E. Crimmins and C. E. Finch 2012. Early cohort mortality predicts the cohort rate of aging: an historical analysis. *Journal of Developmental Origins of Health and Disease* 3(5): 380–386.

Bengtsson, T. and G. Broström 2009. Do Conditions in Early Life Affect Old-age Mortality Directly and Indirectly? Evidence from 19th-Century Rural Sweden. *Social Science and Medicine* 68(9): 1583–1590.

Ben-Shlomo, Y. and D. Kuh 2002. A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. *International Journal of Epidemiology* 31(2): 285–293.

Blum, D. E., S. Chatterji, P. Lloyd-Sherlock, M. McKee, E. Rechel and J. P. Smith 2015. Macroeconomic implications of population ageing and selected policy responses. *The Lancet* 385: 649–657.

Börsch-Supan, A., A. Brugiavini, H. Jürges, J. Mackenbach, J. Siegrist and G. Weber, eds. 2005. *Health, Ageing and Retirement in Europe. First Results from the Survey of Health, Ageing and Retirement in Europe*, Mannheim: Mannheim Research Institute for the Economics of Aging (MEA).

Börsch-Supan, A., M. Brandt, K. Hank, M. Schröder, eds. 2011. *The individual and the Welfare State. Life histories in Europe*. Heidelberg: Springer.

Butler, R. N. 2008. *The longevity revolution: the benefit and challenge of living a long life*. New York: Public Affairs.

Caselli, G. and J. Vallin 2001. Demographic trends: beyond the limits?. *Population: An English Selection* 13(1): 41–72.

Caselli, G. and V. Egidi 2011, Una vita più lunga e più sana. In *Il secolo degli anziani. Come cambierà l'Italia*, ed. A. Golini and A. Rosina, Bologna: Il Mulino.

Christensen, K., G. Doblhammer, R. Rau and J. W. Vaupel 2009. Aging populations: the challenges ahead, *Lancet* 374(9696): 1196–208.

Cohen, J. E. 2005. Human population grows up. In *A pivotal moment*, ed. L. Mazur, 27–37. Washington D.C.: Island Press.

Crimmins, E. M. 2001. Mortality and health in human life spans. *Experimental Gerontology* 36: 885–897.

Crimmins, E. M. 2004. Trends in the health of the elderly. *Annual Review of Public Health* 25: 79–98.

Crimmins, E. M., M. Johnston, M. Hayward and T. Seeman 2003. Age differences in allostatic loads: an index of physiological dysregulation. *Experimental Gerontology* 38: 731–734.

Demakakos, P., J. P. Biddulph, M. Bobak and M. G. Marmot 2015. Wealth and mortality at older ages: a prospective cohort study, *International Journal of Epidemiology and Community Health*. Published Online First 0: 1–8. doi:10.1136/jech-2015-206173.

Doblhammer, G. and J. Kytir 2001. Compression or expansion of morbidity? Trends in healthy-life expectancy in the elderly Austrian population between 1978 and 1998. *Social science and Medicine* 52: 385–391.

Egidi, V. 1992. Cambiamenti delle strutture demografiche e conseguenze economico-sociali, *Atti della* XXXVI Riunione Scientifica della Società Italiana di Statistica. Pescara: SIS, CISU.

Fries, J. F. 1980. Aging, natural death and the compression of morbidity. *The New England Journal of Medicine* 303(3): 130–135.

Fries, J. F. 1989. The compression of morbidity: near or far?. *Milbank Memorial Foundation Quarterly* 67: 208–232.

Fuller-Iglesias, H., J. Smith and T. C. Antonucci 2009. Theories of aging from a life-course and life-span perspective. An overview. *Annual Review of Gerontology and Geriatrics* 29: 3–26.

Higgs, P. and C. Gilleard 2015. *Rethinking old age*, London: Palgrave Macmillan.

Holstein, J. A. and J. F. Gubrium 2000. *Constructing the life course*. AltaMira Press.

Horiuchi, S. and J. R. Wilmoth. 1997. Age patterns of the life table aging for major causes of death in Japan, 1951–1990. *The Journals of Gerontology. Series A: Biological Sciences and Medical Sciences* 52(1): B67–77.

Horiuchi, S., N. Ouellette, S. L. K. Cheung and J.-M. Robine 2013. Modal age at death: lifespan indicator in the era of longevity extension. *Vienna Yearbook of Population Research* 11: 37–69.

Hülür, G., J. Drewelies, P. Eibich, S. Düzel, I. Demuth, P. Ghisletta, E. Steinhagen-Thiessen, G. G. Wagner, U. Lindenberger and D. Gerstorf 2016. Cohort differences in psychosocial function over 20 years: current older adults feel less lonely and less dependent on external circumstances. *Gerontology* 62: 354–361.

Human Mortality Database 2015. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org.

Istat 2013. La salute e il ricorso ai servizi sanitari attraverso la crisi. Roma: Istat, Statistiche Report.

Jagger, C. and J. M. Robine 2011. Healthy Life Expectancy. In *International Handbook of Adult Mortality*, ed. R. G. Rogers and E. M. Crimmins, 551–568. Springer Netherlands.

Jagger, C., H. Van Oyen and J.-M. Robine 2014, *Health expectancy calculation by the Sullivan method: A practical guide*. 4th edition. Newcastle University.

Jeune, B. and V. Kannisto 1997. Emergence of centenarians and super-centenarians, in *Longevity: to the limits and beyond,* ed. J. M. Robine, J. W. Vaupel, B. Jeune and M. Allard, 77–89. Berlin: Springer.

Jones, D., X. Song, A. Mitnitski, K. Rockwood 2005. Evaluation of a frailty index based on a comprehensive geriatric assessment in a population based study of elderly Canadians, *Aging Clinical and Experimental Research* 17: 465–471.

Kahana, E. and Kahana B. 2014. Baby boomers' expectations on health and medicine. *Virtual Mentor* 16(5): 380–384.

Kannisto, V. 1994 *Development of oldest-old mortality 1950–1990: evidence from 28 developed countries.* Odense Monographs on Population Aging No. 1. Odense, Denmark: Odense University Press.

Kannisto, V. 1996. *The advancing frontier of survival: life tables for old age*. Monographs on Population Aging No. 3. Odense, Denmark: Odense University Press.

Kannisto, V. 2000. Measuring the compression of mortality. *Demographic Research* 3(6). doi: 10.4054/DemRes.2000.3.6.

Kannisto, V. 2001. Mode and dispersion of the length of life. *Population-E* 13(1): 159–171.

Kermack, W. O, A. G. McKendrick, P. L. McKinlay 2001. Death-rates in Great Britain and Sweden. Some general regularities and their significance. *International Journal of Epidemiology* 30(4): 678–83.

Lee, R. and Goldstein J. 2003. Rescaling the life cycle: longevity and proportionality. In Life span. Evolutionary, ecological, and demographic perspectives eds. J. R. Carey and S. Tuljapurkar, *Population and Development Review*. Supplement to vol. 29: 183–207.

Legaré, J. and B. Desjardins 1987. Pour une remise en question de l'universalité de l'age normale à la retraite. *European Journal of Population* 3(2): 123–129.

Lutz, W., W. Sanderson and S. Scherbov 2008. The coming acceleration of global population ageing. *Nature* 451: 716–719.

McDonald, R. B. 2014. *Biology of aging*, New York: Garland Science.

Meslé, F. and J. Vallin 2000. Transition sanitaire: tendances et perspectives. *Médecins/Sciences* 16(11): 1161–1171.

Oeppen, J. and J. Vaupel 2002. Broken limits to life expectancy. *Science* 296(5570): 1029–1031.

Oksuzyan A, K. Juel, W. J. Vaupel and K. Christensen 2008. Men: good health and high mortality. Sex differences in health and aging. *Aging Clinical and Experimental Research* 20: 91–102.

Perls, T. T. 2015. Clues for slowing aging. *Scientific American* 24: 100–105.

Pinheiro Melo Borges Tiago, M. T., J. Pedro de Almeida Couto, F. Gomes Borges Tiago and S. M. Costa Dias Faria 2016. Baby boomers turning grey: European profiles. *Tourism Management* 54: 13–22.

Preston S. and H. Wang 2006. Sex mortality differences in the United States: The role of cohort smoking patterns. *Demography* 43(4): 631–646.

Rau, R., E. Soroko, D. Jasilionis and J. Vaupel 2008. Continued reductions in mortality at advanced ages. *Population and Development Review* 34(4): 747–768.

Rice, N. E., A. L. Iain, W. Henley. and D. Melzer 2010. Baby boomers nearing retirement: the healthiest generation? *Rejuvenation Research* 13(1): 105–114.

Robine, J.-M. and C. D. Mathers 1993. Measuring the compression or expansion of morbidity through changes in health expectancy. In *Calculation of health expectancies: harmonization, consensus achieved and future perspectives / Calcul des espérances de vie* *en santé: harmonisation, acquis et perspectives*, ed. J. M. Robine, C. D. Mathers, M. R. Bone and I. Romieu, 269–286. Montrouge: John Libbey Eurotext.

Robine, J. M. and J. W. Vaupel 2002. Emergence of supercentenarians in low-mortality countries, *North American Actuarial Journal* 6(3): 54–63.

Robine, J. M., E. M. Crimmins, S. Horiuchi and Y. Zeng, eds. 2007. *Human longevity, individual life duration, and the growth of the oldest-old population*. Dordrecht: Springer.

Ryder, N. 1975. Notes on stationary populations. *Population Index* 41(1): 3–28.

Sabbath, E. L., C. Matz-Costa, J. W. Rowe, A. Leclerc, M. Zins, M. Goldberg and L. F. Berkman 2015. Social predictors of active life engagement. A time-use study of young-old French adult. *Research on aging*, published online October 8.

Salinari, G. and G. De Santis 2014. Comparing the rate of individual senescence across time and space. *Population-E* 69(2): 165–190.

Sanderson, W. and S. Scherbov 2007. A new perspective on population aging. *Demographic Research* 16: 27–58.

Sanderson, W. and S. Scherbov 2008. Rethinking age and ageing. *Population Bulletin* 63(4).

Sanderson, W. and S. Scherbov 2010. Remeasuring aging, *Science* 329: 1287–1288.

Sanderson, W. and S. Scherbov 2015. Faster increases in human life expectancy could lead to slower population aging. *PLoS ONE* 10(4): 9pp.

Seshamani, M. and A. M. Gray 2004. A longitudinal study of the effect of age and time to death on hospital costs. *Journal of Health Economics* 23: 217–235.

Shammas, M. A. 2011. Telomeres, lifestyle, cancer, and aging. *Current Opinion in Clinical Nutrition & Metabolic Care* 14(1): 28–34.

Shang, B. and D. Goldman 2008. Does age or life expectancy better predict health care expenditures? *Health Economics* 17(4): 487–501.

Soede, A. J., J. C. Vrooman, P. M. Ferraresi and G. Segre 2004. *Unequal Welfare States: Distributive Consequences of Population Ageing in Six European Countries*. The Hague: Center for Research on Pensions and Welfare Policies (CeRP).

Stearns, S. C. and E. C. Norton. 2004. Time to include time to death? The future of health care expenditure predictions. *Health Economics* 13(4): 315–327.

Suzman, R. M., D. P. Willis and K. G. Manton, eds. 1992. *The oldest old*. New York: Oxford University Press.

Twigg, J. and W. Martin, 2015. *Routledge handbook of cultural gerontology*. New York: Routledge.

Van Oyen, H., W. Nusselder, C. Jagger, P. Kolip, E. Cambois and J. M. Robine (2013). Gender differences in healthy life years within the EU: An exploration of the "Health survival paradox". *International Journal of Public Health* 58(1): 143–155.

Zheng, H. 2014. Aging on the context of cohort evolution and mortality selection. *Demography* 51(4): 1295–1317.

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Measuring dependency ratios using National Transfer Accounts

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Abstract

It is now widely recognised that the socio-economic changes that ageing societies will bring about are poorly captured by the traditional demographic dependency ratios (DDRs), such as the old-age dependency ratio that relates the number of people aged 65+ to the working-age population. Compared to the older people of today, future older generations will be in better health, and will likely work longer. However, strictly from a public finance perspective, the extent to which the DDRs capture the challenges that stem from ageing depends on future changes in the age structure of the population, in behavioural patterns, and in age-related public transfers. Combining population projections and National Transfer Accounts (NTA) data (i.e., data on age-specific public transfers), we construct a 'transfer-based' demographic dependency ratio for seven European countries up to 2050. We then compare the quantitative impact of the transfer-based DDR with that of the traditional DDR for three different policy responses to population ageing: net immigration, healthy ageing, and longer working lives. This is done by linking age-specific public health transfers and labour market participation rates to changes in mortality. Four main findings emerge. First, the simple old-age dependency ratio overestimates the future public finance challenges faced by the countries studied, and substantially so for some countries, such as Austria, Finland, and Hungary. Second, healthy ageing (i.e., keeping health transfers constant for a given mortality rate) has a modest effect on public finances, except in the case of Sweden, where it plays an important role. Third, the long-run effect of immigration is captured well by the traditional DDR measure if the common assumption that immigrants are similar to natives is maintained. The immediate to short-term impact of immigration tends to be overstated by the traditional DDR measure. Finally, increasing the average

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length of working life is central to addressing the public finance challenge of ageing. We estimate that extending the average length of working life by three to five years over the next 25 years – roughly in line with the gain in life expectancy – will substantially reduce the impact of ageing on public transfers.

1 Introduction

European societies are ageing. According to Eurostat population projections, the median age of the EU population will increase from 41 in 2010 to 46.4 in 2040. At that time, 26.9% of the population will be aged 65 or older. The well-known causes of these trends are increasing longevity and low fertility in European populations. The challenges posed by these developments for public expenditures related to pensions and health care have often been framed in terms of the concept of the demographic dependency ratio, the old-age burden, or the support ratio; i.e., the ratio of the older population to the working-age population (World Bank 1994; Cutler et al. 1990).

Discussions of the old-age demographic dependency burden, often defined as the number of people aged 65 and older over the number of people aged 20 to 64; have sometimes been supplemented with references to the share of the very old, defined as the number of people aged 85+ over the working-age population, to illustrate that public transfers in the form of health care are particularly large for this very old age group. Thus, projections showing that people will continue to live longer are often, at least implicitly, perceived as being predictions of economic decline, smaller pensions, and lower welfare in general.

Recently, however, a growing number of authors have pointed out that a measure based on chronological age alone is misleading in societies where longevity is increasing substantially with each generation (Sanderson and Scherbov 2007, 2010 and 2013; Lutz 2009; Shoven 2010). Sanderson and Scherbov (2013) argued that it is more appropriate to use a measure such as prospective age; i.e., remaining life expectancy. Using prospective age, the ratio of old to young can be more usefully calculated. For example, we can relate the number of people with less than 15 years of remaining life expectancy to the number of people (or some subset thereof) with more than 15 years of remaining life expectancy. Other measures that account for changes in longevity in similar ways also exist (Sanderson and Scherbov 2013).

Building on this literature, Spijker and MacInnes (2013) have recently gone so far as to call ageing a 'non-problem', at least for the UK. They propose a more dynamic measure that they call a 'real old-age dependency ratio'. Instead of using chronological age, they relate the number of people with a prospective age of less than 15 years to the number of people in employment, arguing that the development in this ratio better reflects the 'old-age burden' and its associated challenges. This approach can be seen as a dynamic version of the simple head-count demographic dependency ratio, in which age cut-off points are moved in tandem with improvements in life expectancy. The authors noted that this measure indicates that the real old-age dependency ratio has been falling since the 1980s in major European countries. The finding that some public transfers depend less on chronological age and more on prospective age suggests that it could make more sense to estimate the old-age burden using a prospective measure of age, such as the real old-age dependency ratio, rather than a measure that is based on chronological age. The cost of individual health care is more closely related to proximity to death than to years from birth (Felder et al. 2000; Bjørner and Arnberg 2012).

While acknowledging the broader point, Barslund and Werder (2014) have challenged this measure, and, in particular, the value of 'backcasting' the real old-age dependency measure. They observed that the National Transfer Accounts (NTAs) (Mason et al. 2006) show that for many countries, pension transfers make up the largest share of public old-age transfers until rather late in life. Until recently, the pension ages in many countries had been unchanged for decades, with a downward trend in the average age of retirement (OECD 2013). The real old-age dependency ratio may be *too* dynamic with respect to implicitly assumed behavioural changes regarding retirement and length of working life, whereas the traditional static old-age DDR is useful for measuring the economic challenges faced by an ageing society absent behavioural changes. In addition, relying on a dynamic measure only could mask the need for policy approaches aimed at changing individual behaviour, particularly related to retirement.

Given this background, the contribution of this paper is relatively modest. In essence, our goal is to shed light on how NTAs can be used to qualify the discussion surrounding ageing and the old-age burden along three important dimensions: namely, health care spending and the concept of healthy ageing, measurements of the impact of migration, and longer working lives. These are the three central building blocks that are needed to evaluate the public finance challenges associated with ageing. In this context, we emphasise that unlike single-country inter-temporal models, which are suitable for investigating detailed budgetary effects, NTAs are especially useful for studying the relative magnitudes of the impacts on public finances of different scenarios over a range of EU countries (Storesletten 2000; Schou 2006; Hansen et al. 2015; Sánchez-Romero 2013; Lassila 2014).

For the purposes of this exercise, we rely on NTAs to provide information on age-specific government (net) transfers, which allow for a more precise assessment of dependency ratios.[1] These data enable us to take into account not just changes in the composition of the population aged 65 and older, but the composition of the working-age population and changes in the number and the composition of dependent young individuals. We call the resulting measure the 'transfer-based

[1] Public net transfers for a given age group are calculated as the sum of monetary transfers (e.g., public pensions) and the value of publicly provided services (e.g., the portion of health care costs covered by the government, as well as other forms of spending, such as on the military or police) less taxes and fees paid for the use of public services.

demographic dependency ratio' or the 'transfer-based' DDR.[2] When looking at the effects of healthy ageing and longer working lives, we link transfers to mortality rates via the given age-transfer link provided by the NTAs. In doing so, we refer to the literature on prospective ageing and more dynamic dependency ratios (see Mason et al. 2015 for a similar approach). The former ratio is a static approach, in the sense that no behavioural changes are assumed; whereas the latter ratio is a dynamic approach, as it is based on the assumption that behaviour changes in response to changes in mortality.

Working at an aggregate multi-country level and with a static framework, we acknowledge upfront the uncertainties surrounding the results. However, as NTAs have become available for a growing number of countries, and country NTAs with different base years and more detailed breakdowns of transfers should be available soon, it is becoming easier to validate our assumptions. Thus, the present approach should yield additional insights into the policy challenges associated with ageing.

First, we find that the simple old-age DDR overestimates the public finance challenges the countries studied are likely to face in the future. In some cases – e.g., for Austria, Finland, and Hungary – this overestimation is substantial. Second, our results show that healthy ageing (i.e., keeping health transfers constant for a given mortality rate) has a modest effect, except in the case of Sweden, where healthy ageing is important. Third, we find that the long-run effect of immigration is well captured by the simple old-age DDR measure if the common assumption that immigrants are similar to natives is maintained, and that the immediate to short-term impact of immigration tends to be overstated by the simple old-age DDR measure. Finally, we show that increasing the average length of working life is essential in tackling the public finance challenges associated with ageing. By linking government transfers to mortality, we project that extending the average length of working life by around 3-5 years over the next 25 years – or roughly in line with the gains in life expectancy – substantially limits the impact of ageing on public transfers.

The remainder of this paper is structured as follows. In the next section, we briefly describe the concept of National Transfer Accounts, and note important caveats that are relevant for our application. This is followed by an outline of the methodology employed. The main results are presented in section 4. Section 5 concludes.

[2] Throughout this article, our suggested NTA-based measure of dependency ratio is called the 'transfer-based' DDR, whereas simple old-age or traditional DDRs refer to head-count measures of the demographic dependency ratio.

Table 1:
Countries covered and reference year

Country	Reference year
Austria	2000
Germany	2003
Finland	2004
Hungary	2005
Slovenia	2004
Spain	2000
Sweden	2003

Source: National Transfer Accounts Project.

2 National Transfer Accounts and population data

The population statistics used in this article are the EUROPOP2013 projections produced by Eurostat,[3] covering all 28 EU countries. We use the base scenario, but detailed assumptions on age-specific fertility, mortality, and net migration are available to facilitate alternative projections. The projection horizon goes from the base year of 2013 to 2080, although the results are presented only up to 2040. The findings are based on a convergence scenario in which the key demographic contributors – fertility and mortality – are assumed to converge towards the same value in the very long run. The central features are an increase in fertility for most countries (exceptions are Ireland, Sweden, and France) and a further increase in life expectancy for all countries, with a convergence towards the values of low-mortality countries. The migration projections are country-specific.

The population projections are paired with NTAs for the seven countries for which they are available from the National Transfer Accounts Project (Table 1).[4]

The concept of NTAs is described concisely and in-depth elsewhere (Mason et al. 2006; Prskawetz and Sambt 2014; UN 2013). Below we outline only the components that are essential to our application, together with a few caveats.

Defined succinctly, an NTA breaks down the most important aggregate economic flows on one-year population age groups for a given year. The flows include public and private consumption, income, and transfers. The flow of transfers, which is the most important component from the point of view of our analysis, is further broken down into transfers related to education, health care, pensions, and other public and private transfers. This breakdown is based on information from micro surveys. The

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[3] A detailed description of the EUROPOP2013 projections is forthcoming. A short description is available from Eurostat (2015) and European Commission (2014). Convergence is achieved in 2150.

[4] See www.ntaccounts.org and Lee and Mason (2011).

aggregates are calibrated by reference to related quantities in the system of national accounts.

Using the information embedded in the age profile of the public transfers in an NTA, it is possible to give a much more detailed description of the impact of changes in the population composition on the public budget. In particular, compared to the traditionally computed DDR,[5] it is possible to assess the effect of changes in the compositions of the populations aged 20–64 and aged 65+. Furthermore, as was emphasised in Hammer et al. (2015), the age limits on when an individual is, on average, a net contributor can be endogenously determined from the transfer profiles.

In this study, we utilise one additional advantage of NTAs: the one-year age-specific transfer profiles allow for a correspondence from mortality (or, almost equivalently, remaining life expectancy) via age to the net transfers in the base year. This allows us to link net transfers (and, implicitly, health status, retirement behaviour, and related labour market participation) to mortality rates in the projection. As an example, Figure 1 shows net public transfers for Germany as a function of (the logarithm of) mortality rates in the base year for the German NTA, together with a mortality age plot. Unfortunately, age-specific transfers are not available beyond age 90.[6] We take transfers to be constant beyond that age.

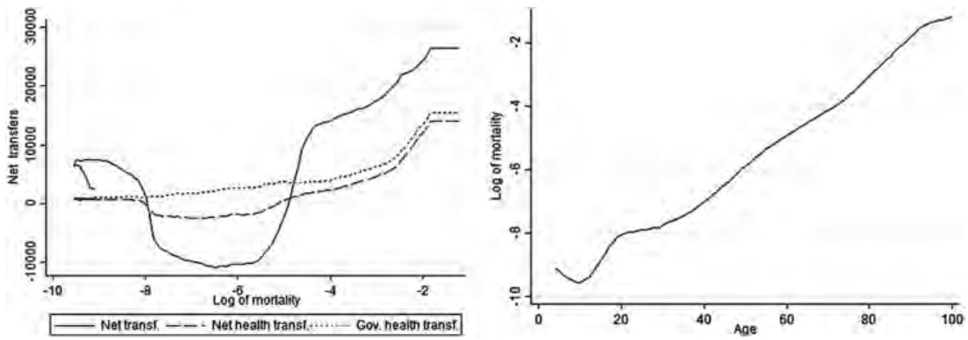
2.1 Caveats and limitations

There are important caveats to the use of NTAs. First, because NTAs build on the system of national accounts, they are only available with a time lag. This means that behavioural changes from recent reforms are not reflected in the data. For example, as the NTA for Germany is from 2003 (Table 1), it predates the Hartz reforms and later reforms to the retirement age. Second, it is important to understand that NTAs are strictly static in nature. Thus, the underlying assumption that is made when using an NTA for a given year to assess transfers in the future is that the world will 'stand

[5] Throughout this paper, we refer interchangeably to the DDR (the number of people aged 65+ over the number of people in the age interval 20 to 64) as the simple DDR, the head-count DDR, the old-age DDR, and the traditional DDR.

[6] For Hungary, no data are available after age 80. The age-specific values for 90+ (80+)-year-olds are derived as population-weighted means of the information available for each of the ages above 90 (80). As such, total transfers will be accurate for the population structure in the base year. To the extent that the population structure of the 90+ population changes (i.e., in our projections), our measures become less accurate. Moreover, it is not clear in which direction the results are biased, as there is evidence that age-specific health care costs decline after the age of 90 (Martini et al. 2007). However, we believe that for two reasons, this will not affect our results materially. First, while the share of 90+-year-olds in the population increases by 2040, it is still small, ranging from 0.8% (Hungary) to 2% (Germany, Finland, and Spain). Second, this is only an issue if the structure of the population aged 90+ changes markedly. For our group of countries, the share of the population aged 95+ within the 90+ population increases by 10 percentage points at most (Austria).

Figure 1:
DE net public transfers as a function of mortality (2013)



Note: The RHS shows logarithmic mortality for each age in 2013. The LHS plots net transfers against logarithmic mortality based on the NTA for Germany in 2003 and the RHS plot.
Source: NTAs and Eurostat.

still'. In addition, our approach does not account for general equilibrium effects; the return to capital and labour will change in response to changes in labour supply and capital accumulation. This poses a problem when the total population changes, and particularly when there is a change in the immigration scenario. The less a small open-economy assumption applies (i.e., for Germany), the more severe the problem. Third, at present, NTAs are only available for a single year. However, because flows are subject to business cycle effects – as is the case for national accounts – measured transfers are not necessarily structural. There is clearly a need to create country NTAs for different years and at different points in the business cycle in order to assess the sensitivity of projection exercises to the base year. While these are clear limitations, some of them, like the dependence on a base year, are not fundamentally different from the challenges posed by the calibration of overlapping generations models.

3 Methodology

The primary objective of this study is to investigate to what extent NTAs enhance our understanding of the challenges to public finances posed by population ageing. While our approach to measuring demographic and economic dependency is, for the most part, standard; the innovation of our methodology lies in the coupling of transfers to mortality rates, as explained below.

Table 2:
Definition of dependency ratios and main scenarios

Name	Description	Definition
	Dependency ratios	
	Simple head count old-age DDR	$\frac{\text{Population aged 65 and older}}{\text{Population aged 20–64}}$
	NTA transfer weighted DDR	$\frac{\sum_{i=1,\ldots,100} \#pop_i \times net\ transfers_i \times I\{net\ transfers_i > 0\}}{\sum_{i=1,\ldots,100} \#pop_i \times net\ transfers_i \times -I\{net\ transfers_i \leq 0\}}$
		Where $\#pop_i$ indicates population at age i, $net\ transfers_i$ are net public transfer at age i,and $I\{\cdot\}$ is an indicator function taking the value one if *true* and zero otherwise.
	Scenarios	
SC1	Immigration	Comparison of the effect of immigration on the simple DDR and on the transfer-based DDR.
SC2	Healthy ageing	Health transfers are assumed to be linked to mortality changes after age 55. This allows for a projection of health transfers *from* the government given changes in age-specific mortality rates.
SC3	Longer working lives	Transfers related to labour market participation are linked exogenously to mortality changes after age 55. This shifts the net transfer curve outwards (see main text and Figure 2).

3.1 Traditional versus transfer-based demographic dependency ratios

Our baseline DDR measure is the traditional count of people above the age of 64 divided by the size of the population between the ages of 20 and 64; i.e., the population who are normally considered to be of working ages (Table 2).[7]

The transfer-based DDR, in contrast, takes into account that the older population is not only increasing in size, but that this population's composition will change as the share of people aged 85 and older grows. This trend is partly a consequence of increasing longevity, and is partly the result of baby boomers moving into this 85+ category with time. However, the transfer-based DDR also accounts for the fact that the age at which net government transfers turn negative is several years below the age of 65. In addition, the age at which contributions (in public finance terms) turn positive for young people is also endogenously determined by the NTAs. Finally, the NTA-adjusted DDR includes transfers to the young. Thus, if the size of the younger population is decreasing, the capacity to sustain a large number of older people increases from a public finance perspective. Both the relative levels of transfers and the age cut-offs differ across countries. These differences are not reflected in the simple DDR measure, but are well accounted for in the transfer-based DDR.

3.2 Scenario 1: Immigration

As immigrants tend to be younger than natives, they may be expected to boost the working-age population relative to the economically dependent population.[8] This improves the simple DDR measure, particularly if it is measured only as the number of older people over the working-age population (Pianese et al. 2014). However, this simpler measure omits two important issues. First, immigrants, like natives, have children, which dampens the positive effect on the transfer-based DDR. Second, the profile of net public transfers is not constant over the working life. Individuals under age 30 contribute less than 45-year-olds because they earn less on average (see Appendix A). Thus, the net contribution by a young immigrant tends to be smaller than the average contribution by the working-age population. By using NTAs to capture the net transfers at each age, we are able to examine how these two issues affect the impact of immigration on the dependency ratio.

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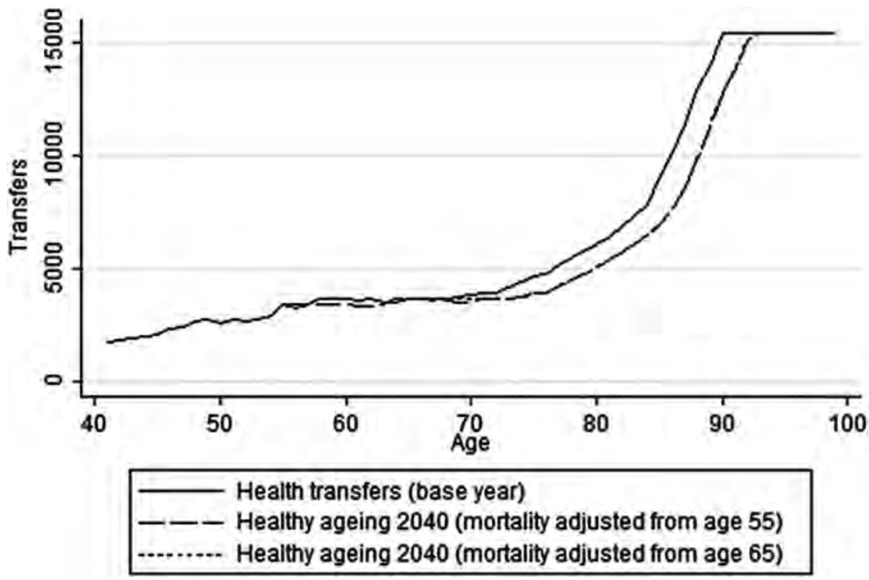
[7] The demographic dependency ratio is often reported for other variations of the definition of the working-age population; i.e., for 15–60-year-olds or 20–60-year-olds. Changing the age cut-off makes no qualitative difference to the reported results.

[8] Under the standard assumption that immigrants are similar to natives in terms of educational composition, labour market participation, health, fertility, etc.

Figure 2:
Government health transfers for healthy ageing scenarios, Germany



Note: Government health transfers in the base year and in 2040 for healthy ageing scenarios for ages 55 and 65, respectively. Health transfers shifted by mortality from age 55 are difficult to see in the figure due to the overlap with the ages 65+ transfer shift line. The line is flat from age 90 in 2000 by design (see the main text above).
Source: NTAs and Eurostat.

3.3 Scenario 2: Healthy ageing

In this scenario, we compare two variants of the transfer-based DDR. In the first measure, the total net transfers, including general transfers and health transfers in particular, are completely age-specific. This measure is equivalent to the transfer-based DDR measure considered in scenario 1 above. In the second measure, we assume that there is one form of healthy ageing, in which healthy ageing implies that public health transfers are fixed for a given mortality rate from age 55 onwards.[9,10] This shifts the government health transfer curve outwards (Figure 2).

Two important assumptions are implicitly embodied in this formulation of healthy ageing. In shifting only the government health transfer curve rather than the net

[9] Results for healthy ageing in the 65 years scenario are also presented (see Appendix A), but they are not materially different. For most countries, the age group 55–65 is on the relatively flat slope of the transfer curve (see Figure 2).

[10] Shifting along a curve of remaining life expectancies yields qualitatively the same results as mortality.

health transfer curve (government health transfers minus privately financed health care costs), we assume that the government reaps the full benefit of lower health care costs for a given age.[11] Second, we implicitly assume that there is no age-related component in (publicly financed) health care costs. As this is likely to be a best-case scenario (Bjørner and Arnberg 2012; Bech et al. 2011; Breyer et al. 2015), it gives us an upper bound for improvement in the transfer-based DDR due to healthy ageing.

Furthermore, implicit in all of our analyses is the assumption of constant relative prices. This could prove problematic if per capita age-related health costs increase considerably due to technological progress (Breyer et al. 2015; Breyer and Felder 2006). We discuss the robustness of our results in light of this potential problem in the results section.

3.4 Scenario 3: Longer working lives

Plans to ensure the sustainability of public finances in the future rely to a large extent on people working longer. This implies that the statutory pension age will have to increase in many countries. However, the statutory pension age as such is not a good metric for assessing the average length of working life, because in many countries the average retirement age is well below the statutory retirement age. In a richer model environment that focuses on country-specific features, assumptions can be made or behaviour can be modelled to show how increases in the statutory retirement age and savings decisions will affect the average length of working life. From such estimates, it is possible to back out the increases in the number of people working, and to relate this number to the number of pensioners (see, e.g., Martín 2010; Fehr et al. 2012; Staubli and Zweimüller 2013; Lassila et al. 2014).

Unlike in much of the literature on ageing and economic sustainability, the focus here is not explicitly on the statutory retirement age. Instead, we seek to simulate a shift in the effective retirement age (or, equivalently, in the labour market employment rates at older ages) that follows projected developments in mortality. There are numerous policy challenges involved in extending the average length of working life. However, we do not consider these challenges in detail, but only note the policy changes implicit in our approach.

Instead, our focus is on determining the effect on the transfer-based DDR measure of an extension of the average working life in line with mortality increases at ages 55 and older. We address this question by linking the relevant transfers to decreases in mortality. The mechanism through which working longer alters the transfer accounts is the postponement of both pension transfers from the government (positive effect on the transfer-based DDR) and the reduction in taxes

[11] This will require policy changes. If patients are required to pay for a portion of their doctors' visits, and healthy ageing means fewer health checkups, then the size of these co-payments will have to increase for the full savings associated with fewer doctors' visits to accrue to the government.

and social contributions stemming from lower employment rates (negative effect). The important components of transfers are pension and health transfers. For pension transfers, this implies an outward shift of the *net* pension transfer curve. This assumption is somewhat in the spirit of Shoven and Goda (2010), who suggested that age limits related to retirement are linked to mortality developments.

For health transfers, only the transfers to the government (via social security contributions and taxes) are shifted outwards along with mortality changes. Health transfers from the government are kept constant at their age-specific values in the base year. These assumptions are the opposite of those made in the healthy ageing scenario. Combining the two scenarios – longer working lives and healthy ageing – would be equivalent to shifting the *net* health transfer curve.

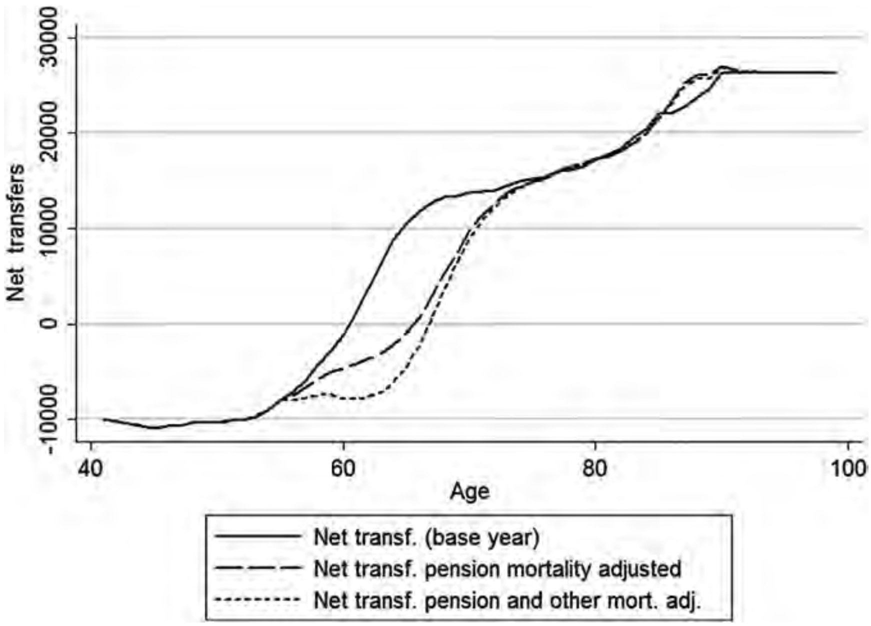
Transfers related to education are shifted as a *net* flow. Because transfers from the government are very small or even zero at the relevant age range for the countries considered here, it makes little difference whether the net flows or the transfers to the government are shifted with mortality changes (see Figure 3). Based on the assumption that transfers to the government related to education are linked to employment rates, we shift the net transfer curve according to changes in mortality and implicit employment rates. For the last component of government transfers, or 'other government transfers', transfers *to* the government have a profile similar to employment rates for the considered age group (50+). We therefore adjust 'other transfers' *to* the government in line with mortality improvements.

Figure 3 shows how the different shifts in the curves of the transfers affect the net government transfers in the case of Germany. The predominant effect comes from shifting the pension net transfer curve as mortality declines. The combined shift in health, other transfers, and education-related transfers to the government has a smaller effect. The net effect of prolonging the average working life in line with mortality improvements from age 55 onwards is to push the age at which net government transfers to individuals turn positive by approximately five years. See Appendix B for the net transfer curves for the other countries.

While it is a somewhat arbitrary choice, age 55 is the age after which labour market participation started to drop off markedly at the time of the reference year (Table 3).[12] Furthermore, one way to interpret the proposed shift is to think of reforms that increase employment rates in line with the projected increase in mortality (life expectancy) without further pension compensation at retirement. We emphasise that this should not be interpreted as a projection since there has been no historical movement in the labour supply response following decreases in mortality (Milligan and Wise 2015). Rather, it is an estimate of the size of the policy challenge of extending the average length of working life.

[12] Labour market participation and employment rates are generally higher at the present time.

Figure 3:
Net government transfers by age, Germany



Note: Government net transfers in the base year and in 2040 for different adjustments.

Table 3:
Labour market participation at ages 50–54 and 55–59 in the reference year for the NTA

		Labour market participation rates		Employment rate	
	Year	**50–54**	**55–59**	**50–54**	**55–59**
Germany	2003	81.4	65.9	74.3	56.4
Spain	2000	66.5	52.7	61.8	48.9
Hungary	2005	71.1	47.4	68.3	46.0
Austria	2000	77.7	49.4	74.3	47.4
Slovenia	2004	75.3	45.4	71.2	43.9
Finland	2004	86.2	65.4	80.1	58.5
Sweden	2003	87.5	81.6	84.9	78.4

Source: EU-LFS, Eurostat.

3.5 Decomposition of changes in DDRs

To make it easier to interpret these results, we decompose changes over time into components that measure population changes between net contributors and net recipients, changes within the group of recipients (and contributors), and changes in average net transfers to and from the government. The change in the transfer-based DDR between t and t + 1 can be decomposed as follows:

$$\Delta TDDR_{t+1,t} \approx \ln\left(\frac{TDDR_{t+1}}{TDDR_t}\right) = \ln\left[\frac{\frac{pop^r_{t+1}}{pop^p_{t+1}} * \frac{avgGtrans^{out}_{t+1}}{avgGtrans^{in}_{t+1}}}{\frac{pop^r_t}{pop^p_t} * \frac{avgGtrans^{out}_t}{avgGtrans^{in}_t}}\right]$$

$$= \ln\left[\frac{pop^r_{t+1}}{pop^r_t}\right] - \ln\left[\frac{pop^p_{t+1}}{pop^p_t}\right] + \ln\left[\frac{avgGtrans^{out}_{t+1}}{avgGtrans^{out}_t}\right] - \ln\left[\frac{avgGtrans^{in}_{t+1}}{avgGtrans^{in}_t}\right]. \quad (1)$$

With pop^r_t being the total population of net recipients of government transfers, receiving an average of $avgGtrans^{out}_t$ per person. Superscript p in pop^p_t denotes the total number of net contributors; i.e., the net transfers to the government. Analogously, for *avgGtrans* a superscript *in* denotes the average amount transferred per person. The two first terms in (1) give the contribution to the transfer-based DDR based on the changes in the relative population shares. Intuitively, if the population of recipients grows faster than the population of contributors, the transfer-based DDR increases. For constant population shares of contributors and recipients, an increase in outgoing transfers (the third term) from the government (due, for example, to the average recipient being older) increases the transfer-based DDR. The opposite is the case when the average transfer to the government increases (fourth term in eq. 1). We denote the effect of the sum of the first and the third terms as the ageing effect, and the effect of the sum of the second and the fourth terms as the support effect. This terminology also facilitates comparisons across scenarios.

For the two scenarios in which we (endogenously) change the age threshold of being a net contributor to government finances – i.e., the healthy ageing and longer working lives scenarios – the decomposition can be further expanded.

Note that we can write:

$$\ln\left(\frac{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{changing mort}}}{\frac{pop^r_t}{pop^p_t}}\right)$$

$$= \ln\left[\frac{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{changing mort}} * \left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{constant mort}}}{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{constant mort}} * \frac{pop^r_t}{pop^p_t}}\right]$$

$$= \ln\left[\frac{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{changing mort}}}{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{constant mort}}}\right] + \ln\left[\frac{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{constant mort}}}{\frac{pop^r_t}{pop^p_t}}\right]$$

$$= \ln\left[\frac{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{changing mort}}}{\left.\frac{pop^r_{t+1}}{pop^p_{t+1}}\right|_{\text{constant mort}}}\right] + \ln\left[\frac{pop^r_{t+1}|_{\text{constant mort}}}{pop^r_t}\right] - \ln\left[\frac{pop^p_{t+1}|_{\text{constant mort}}}{pop^p_t}\right]$$

$$= \ln\left[\frac{pop^r_{t+1}|_{\text{changing mort}}}{pop^r_{t+1}|_{\text{constant mort}}}\right] - \ln\left[\frac{pop^p_{t+1}|_{\text{changing mort}}}{pop^p_{t+1}|_{\text{constant mort}}}\right]$$

$$+ \ln\left[\frac{pop^r_{t+1}|_{\text{constant mort}}}{pop^r_t}\right] - \ln\left[\frac{pop^p_{t+1}|_{\text{constant mort}}}{pop^p_t}\right] \tag{2}$$

where *changing mort* and *constant mort* mean that the expression is evaluated with changing mortality and constant mortality. Focusing on the last line in (2), we see that the two last terms are equivalent to the last two terms in (1). These are the population changes in the absence of mortality adjustments of transfers. The two first terms in (2) are the additional population shifting to, recipients (positive impact on the transfer-based DDR) and 'payers' (negative impact on the transfer-based DDR) as a consequence of the mortality adjustment. Note that these two terms are interdependent, as the total size of the population is given. Thus, the combined impact can be seen as the effect of adjusting transfers by mortality.

The average in and out transfers per person are also affected, and a similar decomposition can be made (not shown).

The simple DDR (SDDR) measure can be decomposed as:

$$\Delta SDDR_{t+1,t} = \ln\left(\frac{SDDR_{t+1}}{SDDR_t}\right) = \ln\left[\frac{pop^{65+}_{t+1}}{pop^{65+}_t}\right] - \ln\left[\frac{pop^{20-64}_{t+1}}{pop^{20-64}_t}\right]$$

In this case, the first term constitutes the ageing effect and the second term constitutes the support effect. We report the relevant decompositions in Appendix C, and refer to the measure throughout the remainder of the text.

4 Results

4.1 Traditional versus transfer-based demographic dependency ratios

Our first main observation is that the simple old-age DDR measure based on head count overestimates the long-run impact of ageing on the public finances of all countries (until 2040); see Table 4. For some countries – namely, Austria, Finland,

Table 4:
Projected developments in traditional and transfer-based DDRs, 2013–40

		2013	2020	2030	2040
Austria	Simple DDR	1	1.09	1.39	1.69
	NTA-based DDR	1	1.13	1.40	1.53
Germany	Simple DDR	1	1.13	1.48	1.82
	NTA-based DDR	1	1.15	1.51	1.71
Finland	Simple DDR	1	1.26	1.48	1.48
	NTA-based DDR	1	1.12	1.23	1.27
Hungary	Simple DDR	1	1.20	1.39	1.59
	NTA-based DDR	1	1.05	1.15	1.40
Slovenia	Simple DDR	1	1.26	1.68	1.96
	NTA-based DDR	1	1.21	1.54	1.77
Spain	Simple DDR	1	1.17	1.52	2.05
	NTA-based DDR	1	1.12	1.46	1.94
Sweden	Simple DDR	1	1.11	1.21	1.29
	NTA-based DDR	1	1.07	1.22	1.28

Source: Own calculations based on EUROPOP2013 and National Transfer Accounts.

and Hungary – the differences between the traditional and the transfer-based DDRs are substantial. These gaps emerge because the NTA transfer-adjusted measure not only includes the younger dependent population, but takes into account the tendency of the younger dependent population to either decline (in some cases substantially), or to increase much more slowly than the older dependent population. This latter factor slows down the overall growth in the population requiring net government transfers. Another factor that is relevant for the countries considered in this study is that government net transfers turn positive between the ages of 56 and 63. The inclusion of this age group in the NTA measure (but not in the simple old-age DDR) reduces the growth in transfers, even if the share of 85+-year-olds is growing (see Table 7 below). This effect would diminish if the age limit for the simple DDR was set at 60 instead of 65. The difference in the denominator plays a smaller role, except for Spain, where negative net transfers from the working-age population decline much faster than in the head-count measure of 20- to 64-year-olds (i.e., the denominator in the old-age DDR measure).

Our second main observation is that there can be substantial differences in the short term. For example, the simple DDR underestimates the population-driven changes in government transfers for Austria and Germany, whereas the opposite is the case for other countries, particularly for Hungary and Finland. For both Germany and Austria, the denominator deteriorates faster; i.e., the support deteriorates towards 2020, as measured by the transfer-based DDR relative to the simple DDR.

Table 5:
Annual net migration assumptions in EUROPOP2013

	Avg. immigration rate 1990–2013 (% of population)	Immigration (% of population)			
		2015	2020	2030	2040
Austria	0.39	0.5	0.6	0.6	0.4
Germany	0.35	0.3	0.3	0.3	0.2
Finland	0.18	0.4	0.4	0.4	0.3
Hungary	0.15	0.2	0.2	0.2	0.3
Slovenia	0.13	0.2	0.2	0.2	0.3
Spain	0.62	−0.2	−0.2	0.2	0.5
Sweden	0.37	0.5	0.5	0.5	0.4

Source: Eurostat and EUROPOP2013.

Around one-half the difference comes from lower average contributions by those who make positive net transfers to the government.

The decomposition into ageing and support effects (Appendix C) illustrates the differences in the nature of ageing across the seven countries and across Europe in general, depending on factors such as past fertility rates (Barslund and von Werder, 2016). For the purposes of illustration, let us look at Finland and Spain: The size of the ageing effect is similar in the two countries, but for Finland, the support effect is negative. That is, the net transfers to the government will increase from the members of the population who make net positive contributions. This effect naturally reduces the rate of growth in the transfer-based DDR. For Spain, the net transfers from contributors decline, and the growth in the transfer-based DDR doubles as a result.

4.2 Scenario 1: Immigration

Our starting point is the projected net migration from the baseline EUROPOP2013. All of the countries are projected to have positive net migration over the full period until 2040 (in fact, until 2080), except Spain, where net migration turns positive around 2025. However, the magnitude of projected migration relative to population varies across countries (Table 5). Sweden and Austria have projected annual net immigration rates of around 0.5% of the population until 2040. Germany and Finland have somewhat lower net immigration rates, while Hungary and Slovenia are projected to have net immigration rates of approximately 0.2%. Spain is projected to have a net emigration rate of 0.2% until 2025, and then somewhat higher-than-average net immigration rates until 2040. These assumed rates are higher than the historical immigration rates for Austria, Finland, Hungary, Slovenia,

Table 6:
Improvements in the simple DDR and government transfer-weighted DDR (%) from immigration relative to a zero-migration scenario

		2013	2020	2030	2040
Austria	Simple DDR	0	−35	−31	−36
	DDR with NTA	0	−22	−30	−40
Germany	Simple DDR	0	−17	−17	−22
	DDR with NTA	0	−8	−14	−21
Finland	Simple DDR	0	−14	−22	−32
	DDR with NTA	0	−17	−27	−36
Hungary	Simple DDR	0	−9	−14	−19
	DDR with NTA	0	−18	−20	−20
Slovenia	Simple DDR	0	−7	−11	−18
	DDR with NTA	0	−4	−12	−21
Spain	Simple DDR	0	6	−1	−11
	DDR with NTA	0	16	7	−6
Sweden	Simple DDR	0	−31	−42	−49
	DDR with NTA	0	−25	−30	−41

Source: Authors' own calculations.

and Sweden. The age distribution of migrants is very similar across countries, with most falling in the 20–30 age bracket (Appendix A).

When we take these assumptions of the EUROPOP2013 projections into account, we see that the demographic dependency ratios of all seven countries are better than they would be without migration (Table 6).

Our main purpose is to explore to what extent the use of NTAs and associated government transfers affect the changes in the DDRs from immigration. The relevant underlying assumption for the use of NTAs is that immigrants display the same behaviour as the average national citizen (in terms of fertility, mortality, and labour market participation), and have the same average endowment with respect to human capital (i.e., the same average wages) and savings.[13]

The total impact of immigration on the DDRs of the different countries will depend on its scale. Table 6 shows the reduction in the change in the DDR due to immigration relative to a zero-migration scenario. Thus, the 35% value of the simple DDR for Austria in 2020 indicates that the growth in the DDR will be reduced by 35% relative to a situation with zero migration. A 100% reduction would mean no future growth in the DDR. These estimates are reported in order to illustrate the

[13] This is not, of course, an innocent assumption (Sébastien 2011). However, exploring the extent to which relaxing this assumption would change the outcome is beyond the scope of this study (see Schou 2006; Hansen et al. 2013 and Ruist 2014).

projected impact of immigration. The main results are the respective differences in the impact from the simple old-age DDR measure and the transfer-adjusted measure of the DDR. From a long-term perspective (up to 2040), the way in which the DDR is measured makes little difference. The simple head count DDR is a good proxy for the impact net migration will have on public finances.

From a short-term perspective (up to 2020), the simple DDR appears to overstate the impact of immigration. As the immigrants are young, their net transfer contributions are still low. But because the immigrants are in the age range in which their fertility is relatively high, negative net transfers from their children may be expected (see Appendix A). For Hungary, the results differ in the short term due to the age structure of the immigrants, as a large share of them are younger than working age.

4.3 Scenario 2: Healthy ageing

Turning to the healthy ageing scenario, we can see that when transfers from the government are shifted with changes in mortality after age 55, there is a great deal of heterogeneity across the countries studied (Table 7). The effect of healthy ageing relative to the baseline transfer-based DDR depends on the change in the composition of the population aged 55 and older, and on the share of the total transfers to the elderly that are health care-related. Since the latter value is not constant across ages, the two effects also interact. To what extent the healthy ageing scenario will reduce the impact of ageing also depends on the steepness of the mortality (age)-specific health transfer curve. A steeper curve implies that healthy ageing has a greater impact on the dependency ratio.

Of the net health and pension transfers to people aged 55 and older, health care transfers make up slightly less than one-third in Slovenia and Sweden, one-quarter in Germany, one-fifth in Hungary, and around 15% in Austria, Spain, and Finland. The change in the age distribution of the population aged 65 and older up to 2040 also varies considerably across these countries. The share of the population aged 85+ will increase by 70% in Finland and Hungary, 50% in Slovenia, and 33% in Germany and Sweden. In Austria and Spain, the age distribution will remain relatively constant, with the number of 85+-year-olds increasing slightly faster than the overall number of 65+-year-olds.

In Austria and Hungary, healthy ageing is projected to have little impact up to 2040. Health care makes up a smaller share of overall transfers in these two countries than in the other countries studied. The largest impact is found for Sweden, where healthy ageing reduces the projected increase in the DDR by more than one-third. Minor effects are found for Germany, Slovenia, and Spain. When we look at the decomposition in Appendix C, we see that healthy ageing has a negligible support effect. A small effect comes from slightly larger net transfers due to a decrease in government health care transfers (an effect that is not visible in the appendix due to rounding). Similarly, the main ageing effect comes from a decrease

Table 7:
Health care transfers (% of total transfers) and results from the healthy ageing scenario

	Average share of health care in transfers	Share of 85+ in % of 65+		Increase in transfer-based DDR (index). Healthy ageing	Reduction in transfer–based DDR under healthy ageing relative to baseline (%)
	2013	2013	2040	2040	2040
Austria	0.12	0.14	0.16	1.51	4
Germany	0.26	0.13	0.18	1.63	11
Finland	0.16	0.13	0.22	1.24	11
Hungary	0.22	0.11	0.18	1.37	7
Slovenia	0.28	0.12	0.18	1.68	12
Spain	0.16	0.15	0.17	1.84	11
Sweden	0.29	0.15	0.19	1.17	39

Source: Own calculations based on National Transfer Accounts.

in net transfers. An exception is Spain, where the threshold for the age at becoming a net contributor changes from 60 to 62 in the healthy ageing scenario. As a result, the average net transfers from the government for support recipients go up, while the number of people being supported declines.

Apart from the fact that the health transfers are (much) smaller than the pension transfers (see Appendix D), the steepness of the age-transfer curve (in the base year) also differs for pension and health transfers. For all of the countries, the net pension transfer curve has a steeper age gradient than the health curve, although the difference is less pronounced for Sweden. This implies that as countries age, net health transfers become less important relative to pension transfers.

If healthy ageing means that health care costs are reduced by less than the reduction in mortality, the impact on the transfer-based DDR is proportionally smaller.

As noted above, there is some evidence that per capita age-related health costs grow faster than income and prices in general (Breyer and Felder 2006). Such a scenario is inconsistent with our 'constant world' assumption. However, we can get some idea of how a 1% annual increase in age-related per capita costs would affect our results by shifting the government health transfer curve by 1% annually. This is a worst-case scenario relative to our assumptions, because it implies that health care contribution transfers to the government stay fixed. An annual 1% growth rate up to 2040 would mean that age-specific transfers would be around 30% higher in 2040. In this case, a healthy ageing scenario would lead to a greater reduction in the growth in the transfer-based DDR up to 2040, because health transfers would be a larger share of total transfers in 2040. Under such a scenario, healthy ageing becomes increasingly important. For Germany, Spain, Finland, and Slovenia, healthy ageing now limits the growth in the transfer-adjusted DDR by 25% to 30%. For Hungary and Austria, the equivalent figure is 20%. In Sweden, where healthy ageing has a large impact in the base scenario, the increase in the transfer-based DDR is 60% smaller.

Given these results, we are cautious about putting too little emphasis on the role of healthy ageing in the sustainability of public finances, even if in most countries the impact of healthy ageing on the transfer-adjusted DDR of pension transfers dwarfs that of health transfers.

4.4 Longer working lives

For the seven countries considered here, the shift in the transfer curve is equivalent to a shift in behaviour of around five years. Thus, in 2040, a 60-year-old is assumed

Table 8:
Increases in the length of working life, 2013–2040

	Reference Year	Labour market participation rate	Extension of working life, years	Duration of working life, base year	Shift in transfer schedule, years
Germany	2003	73.7	4.1	34.3	5.6
Spain	2000	59.6	3.3	31.6	5.5
Hungary	2005	59.3	5.1	28.0	8.6
Austria	2000	63.6	3.1	34.6	4.9
Slovenia	2004	60.4	3.7	33.2	6.2
Finland	2004	75.8	4.2	36.4	5.5
Sweden	2003	84.6	3.8	38.5	4.5

Source: Authors' own calculations.

to have the same behaviour – with respect to labour market participation – as a 55-year-old had in the base year.[14]

Based on labour market participation rates from Eurostat's labour force statistics (see Table 3 above), we make assumptions about the labour force participation of 55-year-olds for the reference year of the country's NTA (Table 8), and implicitly assume that the difference between labour force participation and employment is structural in the reference year.[15] To arrive at the implied increase in the average working life for each country, the labour market participation rate is multiplied by the implicit number of working years – i.e., between 4.5 (Sweden) and 8.6 (Hungary) – by which the transfer schedule is shifted (Table 8). For Germany, the labour force participation rate in the base year of a 55-year-old is calculated to be 73.7. Extending this rate to age 60.6 (adding 5.6 years to 55) in line with mortality improvements adds 4.1 working years to the average length of working life.

The increase in the average length of working life has a substantial impact on demographic dependency ratios. In Germany, Spain, and Austria, the expansion of the demographic dependency ratio is reduced by more than one-half (Table 9). In Finland, the transfer-based DDR will be a little larger in 2040 than it is today. In Sweden, the DDR will grow by just 15% by 2040. The effect for Slovenia is somewhat smaller. The result for Hungary arises because the transfer-based DDR not only grows more slowly as a consequence of the increase in the average working life, but is actually reduced relative to the base year transfer-adjusted DDR.

14 Informally, we think of this as the average individual maintaining his or her labour market participation behaviour between ages 55 and 60, paying taxes, and making health and pension contributions, but *without* any compensation in the form of higher pensions.

15 The employment rate at age 55 is assumed to be the average over the (average) employment rates for the age groups 50–54 and 55–59.

Table 9:
Improvement in the transfer-adjusted DDR (%) in the longer working life scenario (reduction in the growth of the transfer-based DDR)

	2013	2020	2030	2040
Austria	0	57	53	58
Germany	0	66	61	56
Finland	0	66	73	92
Hungary	0	215	173	130
Slovenia	0	28	30	35
Spain	0	65	58	57
Sweden	0	85	74	85

Note: The effect of a longer working life scenario is measured by the reduction in the growth of the DDR towards 2040.
Source: Authors' own calculations.

The decomposition of the changes relative to the baseline transfer-based DDR shows that the change (in absolute percentage points) in the ageing effect is rather uniform across the countries, with the exception of Hungary. The larger decrease in the ageing effect is due to the relatively long extension of the average working life (cf. Table 8). The support effect shows more variation (Appendix D). In particular, it explains the relatively subdued effect for Slovenia, despite the substantial prolongation of the average working life. The shift in the net transfer curve in the case of Slovenia improves the support effect only marginally (the effect is not detectable with two decimals in the table) because the net transfer contributions to the government of 55-year-olds are marginal.

The reported scenario for longer working lives builds upon the EUROPOP2020 baseline population projections, including immigration, as outlined above. If the healthy ageing scenario is added, the increase in the DDR is reduced by some additional percentage points.

To meet the fiscal challenges associated with ageing, it is essential that people work longer. For most countries, the effect of an increase in the average length of working life dwarfs the potential effect of increasing immigration or healthy ageing. Changes in retirement behaviour, and therefore in the average length of working life, do not occur automatically as longevity rises and health improves. In fact, from a life-cycle consumption model point of view, it may be optimal to spend more time in retirement as longevity increases (Bloom et al. 2014; Leinonen et al. 2015). What is presented here is a best-case scenario, in terms of both behavioural responses and the speed of policy-induced changes. In our simulation, the effect on the transfer-based DDR is roughly proportional to the assumed lengthening of the average working life as a function of mortality.

5 Conclusion

In this study, we presented a transfer-based demographic dependency ratio that takes into account a number of important features of on-going demographic changes, not least from a public finance perspective. Our measure takes into account the decline in the number of young people in many countries, and assumes that the transfers to this segment of the population will therefore be reduced. It also takes into account the large variations in the net transfers to older people depending on their age. This means that the composition of the older population is important, a factor that the simple DDR ignores. Furthermore, the transfer-based DDR explicitly acknowledges that the age range in which people are net contributors to public transfers, rather than net recipients of public transfers, varies across countries. Finally, the new measure also accommodates changes in the composition of net contributors (or the working-age population). None of these demographic developments are reflected in the simple DDR measure.

Our results suggest that care is needed when assessing the impact of population ageing using the simple head-count measure of the demographic dependency ratio. Our application of the transfer-based DDR indicates that the simple measure can significantly distort the challenges ahead in a negative direction.

The transfer-based DDR allowed us to simulate the impact of healthy ageing and extended working lives under different assumptions. The baseline definition of healthy ageing used here linked government health transfers to mortality developments for different age groups. As we noted above, this is likely a best-case scenario because it assumes no direct effect of chronological age after mortality is accounted for. Generally, however, healthy ageing was found to make little difference in the increase in net public transfers driven by demographics. If health care costs increase in relative terms, this could change the impact of healthy ageing because the health transfer component of net transfers to older people would increase in size. Of course, this result implies that the public finance challenges associated with ageing would increase as well.

For the longer working lives scenario, our starting point was the literature on prospective ageing. We implicitly assumed that labour market behaviour, and hence associated transfers, changes with mortality after age 55. Transfers related to labour market behaviour become a function of mortality. The results point to an increase in the average length of working life of three to five years. For most of the countries studied, this shift is associated with a decisive reduction in the increase in projected net public transfers.

Finally, we wish to stress the uncertainties involved in such multi-country macro projections. Nevertheless, we believe that the methods applied here can prove useful when comparing countries and when assessing the broad impact of policy initiatives. As National Transfer Accounts become available for more countries and for more years, there is further scope for the cross-validation of the assumptions made and the results generated in this study.

References

Barslund, M. and M. v. Werder 2014. Online comment on: Population ageing: the time bomb that isn't?, *British Medical Journal* (www.bmj.com/content/347/bmj.f6598/rr/760129).

Barslund, M., and M. von Werder 2016. Measuring ageing and the need for longer working lives in the EU, CEPS Working Document No. 417.

Bech, M., T. Christiansen, E. Khoman, J. Lauridsen and M. Weale 2011. Ageing and health care expenditure in EU-15, *European Journal of Health Economics* 12(5): 469–478.

Bloom, D. E., D. Canning and M. Moore 2014. Optimal retirement with increasing longevity. *The Scandinavian Journal of Economics* 116(3): 838–858.

Bjørner, T. B. and S. Arnberg 2012. Terminal costs, improved life expectancy and future public health expenditure, *International Journal of Health Care Finance and Economics* 12(2): 129–143.

Breyer, F. and S. Felder 2006. Life expectancy and health care expenditures: a new calculation for Germany using the costs of dying, *Health Policy* 75(2): 178–186.

Breyer, F., N. Lorenz and T. Niebel 2015. Health care expenditures and longevity: is there a Eubie Blake effect?, *European Journal of health economics*, 16(1): 95–112.

Cutler, D. M., J. M. Poterba, L. M. Sheiner and L. H. Summers 1990. An Aging Society: Opportunity or Challenge?, Brooking Papers on Economic Activity 1990(1): 1–73.

European Commission 2014. The 2015 Ageing Report: Underlying Assumptions and Projection Methodologies, DG EcFin, European Commission.

Eurostat 2015. EUROPOP2013 – Population projections at national level (http://ec.europa.eu/eurostat/cache/metadata/en/proj_13n_esms.htm).

Fehr, H., M. Kallweit and F. Kindermann 2012. Pension reform with variable retirement age: a simulation analysis for Germany, *Journal of Pension Economics and Finance* 11(03), 389–417.

Felder, S., M. Meiers and H. Schmitt 2000. Health care expenditure in the last months of life, *Journal of Health Economics* 19(5): 652–695.

Hammer, B., A. Prskawetz and I. Freund 2015. Production activities and economic dependency by age and gender in Europe: A cross-country comparison, *Journal of the Economics of Ageing* 5: 86–97.

Hansen, M., M. L. Schultz-Nielsen and T. Tranæs 2015. The Impact of Immigrants on Public Finances: A Forecast Analysis for Denmark, IZA Discussion Paper No. 8844, Institute for the Study of Labor.

Lassila, J., N. Määttänen and T. Valkonen 2014. Linking retirement age to life expectancy–what happens to working lives and income distribution?, Reports 02/2014, Finnish Center for Pensions.

Lutz, Wolfgang 2009. The Demography of Future Global Population Aging: Indicators, Uncertainty, and Educational Composition, *Population and Development Review* 35(2): 357–365.

Lee, R. and A. Mason 2011. *Population aging and the generational economy: A global perspective*. Edward Elgar, Cheltenham, UK (http://www.idrc.ca/EN/Resources/Publications/openebooks/514-4/index.html#list).

Leinonen, T., P. Martikainen and M. Myrskylä 2015. Working life and retirement expectancies at age 50 by social class: Period and cohort trends and projections for Finland. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, gbv104.

Martín, A. R. S. 2010. Endogenous retirement and public pension system reform in Spain, *Economic Modelling* 27(1): 336–349.

Mary Martini, E., N. Garrett, T. Lindquist and G. J. Isham 2007. The boomers are coming: A total cost of care model of the impact of population aging on health care costs in the United States by major practice category, *Health Services Research* 42(1p1): 201–218.

Mason, A., R. Lee, A-C Tung, M-S Lai and T. Miller 2006. Population Aging and Intergenerational Transfers: Introducing Age into National Accounts, NBER Working Paper 12770, National Bureau of Economic Research (http://www.nber.org/papers/w12770).

Mason, A., R. Lee, D. Stojanovic and M. Abrigo 2015. The Fiscal Impact of Population Aging: Accounting for the Role of Demography, Manuscript version dated 26 February 2015.

Milligan, K. and D. A. Wise 2015. Health and Work at Older Ages: Using Mortality to Assess the Capacity to Work across Countries, *Journal of Population Ageing* 8: 27–50.

OECD (2013), *Pensions at a Glance 2013: OECD and G20 Indicators*. OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/pension_glance-2013-en.

Pianese, A., A. Attias and Z. Varga 2014. Dynamic immigration control improving inverse old-age dependency ratio in a pay-as-you-go pension system, *Decision Support Systems* 64: 109–117.

Prskawetz, A. and J. Sambt 2014. Economic Support Ratios and the Demographic Dividend in Europe, *Demographic Research* 30: 963–1010.

Ruist, Joakim 2014. Free immigration and welfare access: The Swedish experience, *Fiscal studies* 35: 19–39.

Sánchez-Romero, M., J. Sambt and A. Prskawetz 2013. Quantifying the role of alternative pension reforms on the Austrian economy, *Labour Economics* 22: 94–114.

Sanderson, W. C. and S. Scherbov 2007. A new perspective on population ageing, *Demographic Research* 16(2).

Sanderson, W. C. and S. Scherbov 2010. Remeasuring ageing, *Science* 329: 1287–1288.

Sanderson, W. C. and S. Scherbov 2013. The characteristics approach to the measurement of population aging, *Population Development Review* 39(4): 673–685.

Sébastien, Jean et al. 2011. Migration and labour market outcomes in OECD countries, *OECD Journal: Economic Studies* 2010/1 (DOI: http://dx.doi.org/10.1787/eco_studies-2010-5kmhf827kws6).

Schou, P. 2006. Immigration, integration and fiscal sustainability, *Journal of Population Economics* 19(4): 671–689.

Shoven, J. B. 2010. New Age Thinking: Alternative Ways of Measuring Age, Their Relationship to Labor Force Participation, Government Policies, and GDP, in *Research Findings in the Economics of Aging*, Chicago, IL: University of Chicago Press.

Shoven, J. B. and G. S. Goda 2010. Adjusting Government Policies for Age Inflation, in J. B. Shoven (ed.), *Demography and the Economy*, Chicago, IL: University of Chicago Press.

Spijker, J. and J. MacInnes 2013. Population ageing: the time bomb that isn't, *British Medical Journal* 347: f6598.

Staubli, S. and J. Zweimüller 2013. Does raising the early retirement age increase employment of older workers?, *Journal of Public Economics* 108: 17–32.

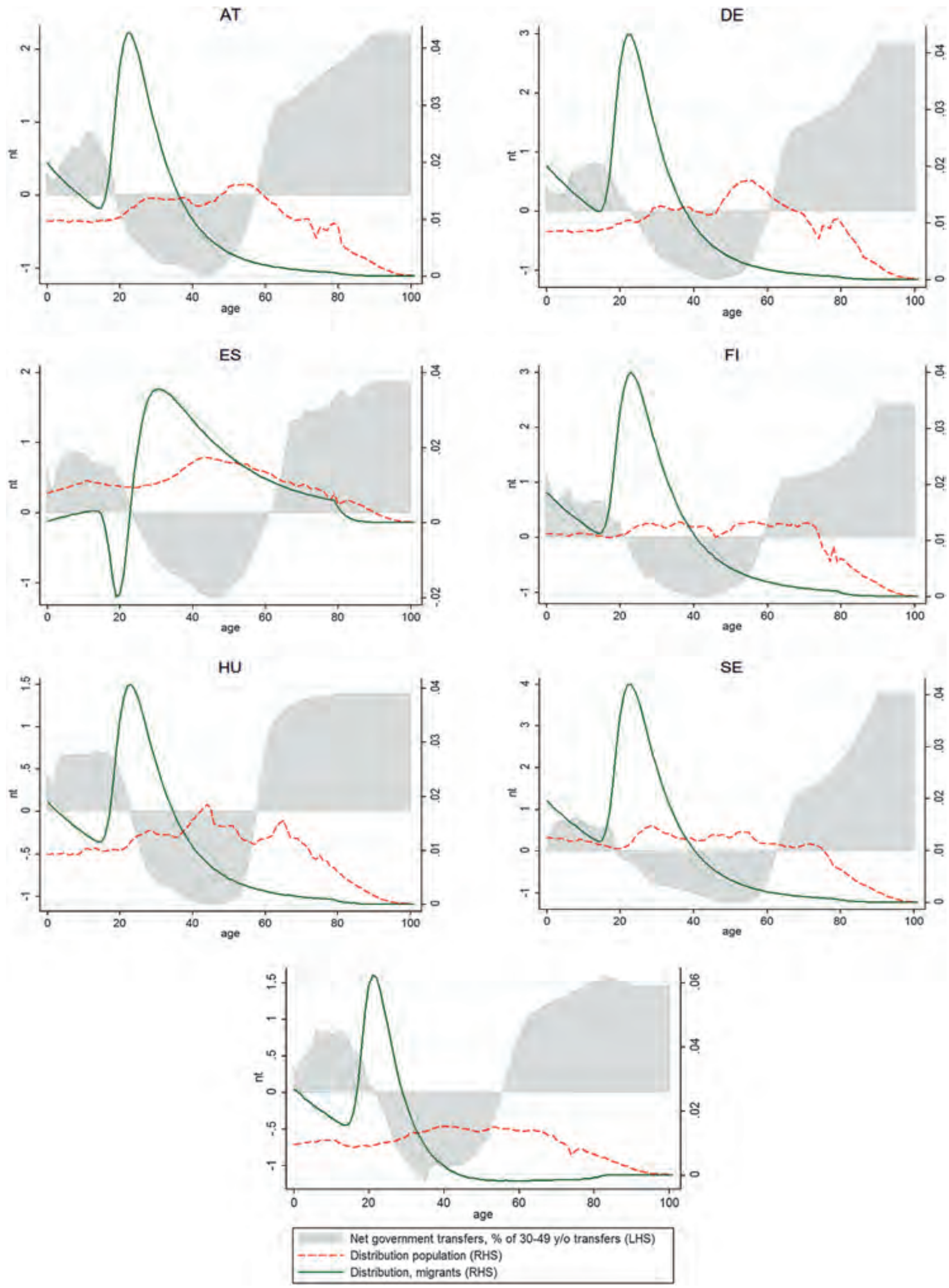
Storesletten, K. C. 2000. Sustaining fiscal policy through immigration, *Journal of Political Economy* 108: 300–323.

UN 2013. National Transfer Accounts Manual: Measuring and Analysing the Generational Economy. United Nations, Department of Economic and Social Affairs, Population Division. (http://www.un.org/en/development/desa/population/publications/development/NTA_Manual.shtml).

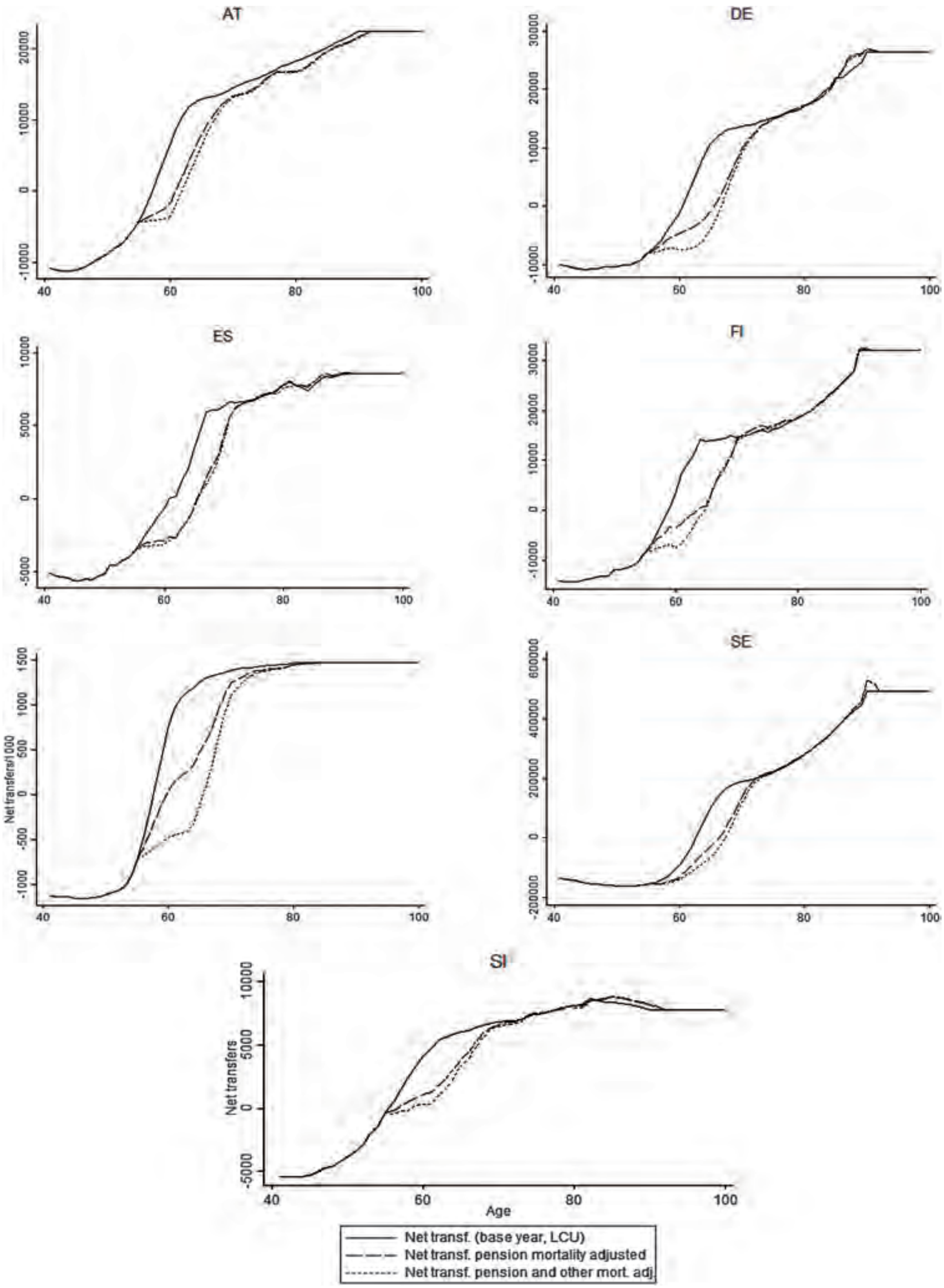
World Bank 1994. *Averting the old age crisis: policies to protect the old and promote growth*, Washington, D.C. (http://documents.worldbank.org/curated/en/1994/09/698030/averting-old-age-crisis-policies-protect-old-promote-growth).

Appendices follow

Appendix A: Age structure of migrants and natives together with government net transfers (relative to average net transfers for 25–54-year-olds)



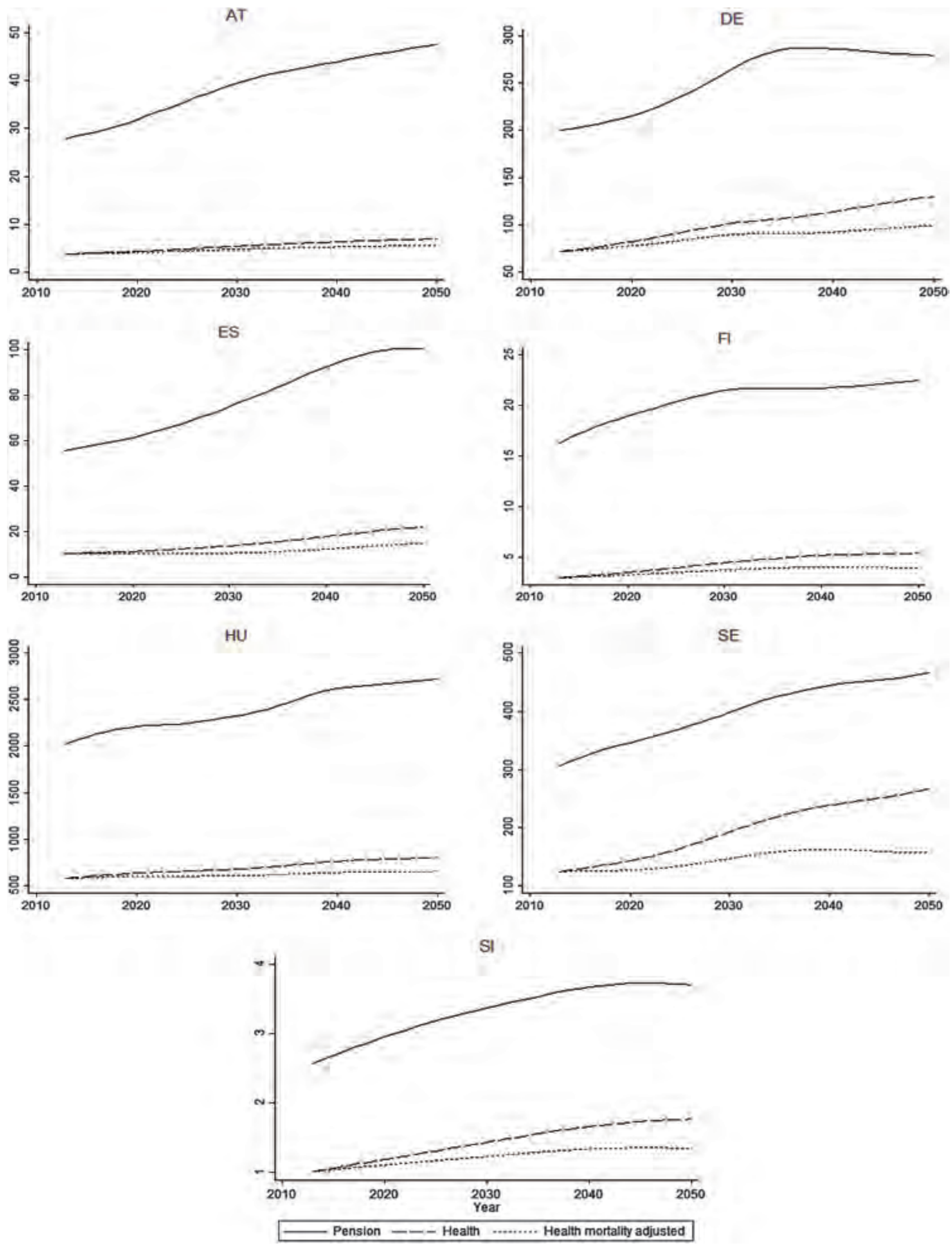
Appendix B: Net government transfers by age and scenario



Appendix C: Decomposition of the total growth in demographic dependency ratios (different scenarios)

	Δ2013–2040	Ageing	Support	Decompose Ageing		Decompose Support		Total	Ageing	Support	Decompose Ageing		Decompose Support	
		share	share	Popul.	Transf.	Popul.	Transf.		share	share	Popul.	Transf.	Popul.	Transf.
	Traditional DDR													
DE	0.60	0.37	0.22											
FI	0.39	0.41	−0.02											
ES	0.72	0.51	0.21											
SE	0.25	0.39	−0.13											
SI	0.67	0.51	0.16											
AT	0.53	0.53	0.00											
HU	0.46	0.32	0.15											
	Transfer-based DDR													
DE	0.54	0.28	0.25	0.12	0.16	0.24	0.01							
FI	0.24	0.29	−0.05	0.17	0.12	−0.04	−0.01							
ES	0.66	0.30	0.37	0.18	0.12	0.28	0.09							
SE	0.25	0.39	−0.15	0.29	0.11	−0.14	−0.01							
SI	0.57	0.31	0.26	0.19	0.12	0.22	0.04							
AT	0.43	0.40	0.03	0.28	0.11	0.02	0.01							
HU	0.34	0.17	0.17	0.08	0.09	0.18	−0.01							
	Transfer-based DDR-healthy ageing							**Relative changes of transf.-based to healthy ageing DDR (p.pt.)**						
DE	0.49	0.24	0.25	0.12	0.12	0.24	0.01	−0.05	−0.04	0.00	0.00	−0.04	0.00	0.00
FI	0.21	0.26	−0.05	0.17	0.10	−0.04	−0.01	−0.03	−0.03	0.00	0.00	−0.03	0.00	0.00
ES	0.61	0.26	0.36	0.12	0.14	0.21	0.15	−0.05	−0.04	−0.01	−0.06	0.02	−0.07	0.06
SE	0.16	0.31	−0.15	0.29	0.02	−0.14	−0.01	−0.09	−0.09	0.00	0.00	−0.09	0.00	0.00
SI	0.52	0.26	0.26	0.19	0.07	0.22	0.04	−0.05	−0.05	0.00	0.00	−0.05	0.00	0.00
AT	0.41	0.38	0.03	0.28	0.09	0.02	0.01	−0.02	−0.02	0.00	0.00	−0.02	0.00	0.00
HU	0.31	0.15	0.17	0.08	0.07	0.18	−0.01	−0.02	−0.02	0.00	0.00	−0.02	0.00	0.00
	Transfer-based DDR-longer working lives							**Relative changes of transfer-based to longer working lives DDR (p.pt.)**						
DE	0.27	0.13	0.14	−0.01	0.14	0.09	0.05	−0.27	−0.16	−0.11	−0.13	−0.03	−0.15	0.04
FI	0.02	0.16	−0.13	0.04	0.12	−0.18	0.05	−0.22	−0.14	−0.08	−0.13	−0.01	−0.14	0.06
ES	0.34	0.12	0.21	0.02	0.10	0.11	0.11	−0.32	−0.17	−0.15	−0.16	−0.02	−0.18	0.02
SE	0.04	0.27	−0.23	0.17	0.11	−0.23	0.00	−0.21	−0.12	−0.09	−0.12	0.00	−0.09	0.01
SI	0.41	0.15	0.26	0.17	−0.02	0.19	0.07	−0.16	−0.16	0.00	−0.02	−0.14	−0.03	0.03
AT	0.20	0.22	−0.02	0.19	0.03	−0.07	0.05	−0.22	−0.17	−0.05	−0.10	−0.08	−0.10	0.05
HU	−0.13	−0.17	0.04	−0.16	0.00	−0.07	0.11	−0.47	−0.33	−0.13	−0.24	−0.09	−0.25	0.12

Appendix D: Net total transfers (bn. LCU) to people aged 55+ (pension, health, and health adjusted for mortality changes)



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Subjective survival expectations and observed survival: How consistent are they?

Alberto Palloni and Beatriz Novak*

Abstract

In this paper, we use new models to convert subjective expectations elicited from individual responses into conditional survival functions. We also estimate the effects of individual characteristics and assess the impact of health shocks on individual updates of subjective expectations. We use Health and Retirement Study (HRS) data from 1992 to 2006. By and large, our results confirm past empirical findings, but also identify patterns not documented in previous research. We show that the subjective probabilities are remarkably close to the results of actual life tables constructed from observed data, that whites underestimate their survival chances more than blacks, that women underestimate their survival chances more than men, and that the subjective underestimation of conditional survival increases with age in all population subgroups. We find significant differences in the survival outlooks of the original HRS cohort and a more recent HRS cohort (1992 versus 2004). These differences persist after introducing suitable controls. The observed mortality differentials between smokers and non-smokers, obese and non-obese individuals, and high-education and low-education groups are quite close to those of these subgroups' subjective survival expectations. Finally, we find large updating effects that result from recent health shocks on subjective expectations.

1 Introduction

Subjective survival expectations are responses to questions about the probabilities of surviving to selected target ages that respondents could attain in the future. The strategies used to elicit probabilistic appraisals from individuals are quite diverse, but the standard tools are based on variants of a question such as this: "Using

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a number between 0 and 1, where 0 is lowest and 1 is highest, what would you say is the probability that you will survive to age *X* (or *Y* more years)?" Work on survival expectations is relatively new, and is part of a larger literature on individual expectations (Manski 2004). The interest in this topic has been growing rapidly as researchers uncover patterns and varying degrees of consistency of subjective expectations with individual objective health status and changes thereof (Liu et al. 2007), past and current health-related behaviors (Falba and Busch 2005; Khwaja et al. 2006 and 2007; Scott-Sheldon et al. 2010), experiences of health shocks, and individual self-reported health (Smith et al. 2001a).

This paper has two modest goals. First, we seek to evaluate the degree of consistency between conditional survival probabilities computed from subjective survival expectations and conditional survival probabilities from observed life tables in two cohorts of older adults from the Health and Retirement Study (HRS). To do so, we employ models and strategies that partially resolve well-known problems of subjective expectation data. Second, we estimate the effects of individual traits (obesity), behaviors (smoking), and experiences with health shocks on subjective survival probabilities, and assess how these effects vary by age, race, and gender.

In this paper, we seek to confirm empirical results obtained by past research, and to introduce a handful of new ideas and findings. First, we propose semi-parametric, relational models that capture robustly the effects of individual traits, behaviors, and health shocks on the formation and updating of subjective expectations. Second, we perform extensive – albeit tedious – sensitivity analyses to assess the magnitude of the estimates' uncertainty that is attributable to a recurrent problem of subjective expectations; namely, the large shares of focal[1] and inconsistent responses.[2] Third, we identify and account for the phenomenon whereby older individuals tend to underestimate their survival chances (relative to their objective chances) by a larger margin than younger individuals. Finally, we add new empirical evidence to the literature about the direction and the magnitude of the updating of individual expectations as a reaction to recent health shocks (Khwaja et al. 2006; Liu et al. 2007; Smith et al. 2001a and 2001b).

The outline of the paper is as follows. In section 2, we review selected empirical findings. In section 3, we describe the data, including the advantages and disadvantages of our dataset. In sections 4 and 5, we introduce definitions, describe the models, and review the results. We present our conclusions in the final section.

[1] A focal response is an answer given to a question in which the respondent is asked about his or her beliefs regarding the probability of the occurrence of any given future event that corresponds to a probability equal to zero, one-half, or one (Hurd and McGarry 1995).

[2] In this paper, inconsistency occurs when the implied probability of surviving to age y is lower or equal to the implied probability of surviving to age x, $x > y$.

2 Subjective survival expectations, health, and mortality

While self-rated health status (SRH) reflects a combination of specific information and knowledge about recent or current health problems, physical functioning, and health-related behaviors (Quesnel-Vallée 2007), subjective survival expectations may capture some richer dimension that is unlikely to be included in self-rated health status (Popham and Michell 2007). It has been posited that these expectations reflect information about genetic or hereditary susceptibilities (Balia 2007, Hurd and McGarry 1995; Perozek 2008; Roebuck Bulanda and Zhang 2009); knowledge of the health conditions of parents, siblings, or other kin (Zick et al. 2014; van Doorn and Kasl 1998); assessments of past or current exposures to environmental and behavioral risk factors not captured by standard surveys questionnaires (Perozek 2008); and experiences of health trajectories over time (Benítez-Silva and Ni 2008).

There is abundant evidence showing that self-rated health status is a consistently robust independent predictor of mortality, even after accounting for relevant covariates, such as objective health status indicators (Idler and Benyamini 1997; Singh-Manoux et al. 2007; Young et al. 2010). Since research on subjective survival expectations is a new area of health research, it is not yet widely known that these expectations have been shown in some analyses to be good predictors of individual mortality, even after controlling for socio-demographic factors and health-related conditions (Hurd et al. 1999; Hurd and McGarry 2002; Perozek 2008; Smith et al. 2001b). However, these outcomes are not uniformly supported by all empirical findings, and some researchers continue to be skeptical about their power (Elder 2013). More surprisingly, although it has been shown that subjective survival expectations are empirically related to self-rated health, and that these indicators are roughly consistent with each other, there is evidence that survival expectations tap different dimensions of individual health vulnerabilities (Hurd and McGarry 1995; van Doorn and Kasl 1998), and are independent predictors of both individual and aggregate mortality, net of the effects of self-rated health (Siegel et al. 2003; van Doorn and Kasl 1998).

Recent research on subjective survival expectations has identified four important patterns.

First, individual subjective probabilities of survival are roughly consistent with observed (life table) probabilities, exhibit the expected levels of covariation with characteristics such as socioeconomic status and smoking (Hudomiet and Willis 2012; Hurd and McGarry 1995), are roughly consistent with population-based observed survival patterns, and track remarkably well with observed individual survival trajectories (Smith et al. 2001b; Hurd and McGarry 2002) As Smith and colleagues stated in their study of HRS data, "… [the] evolution of subjective probabilities does appear to include an expectational component that may incorporate unobservable features of personal circumstances that bear on survival to age 75" (Smith et al. 2001b: 1131).

Second, survival expectations track reasonably well with *changing* mortality conditions. Thus, in some of the most thorough work to date using HRS data, Perozek (2008) found that subjective expectations elicited from the 1992 HRS predict the direction of revisions to the Social Security Administration (SSA) life tables between 1992 and 2004. Studies based on the European SHARE data lend support to this observed pattern, and lead to similar inferences (Peracchi and Perotti 2012). However, the degree of accuracy with which subjective expectations "foresee" or track mortality changes is contingent upon and influenced by the age of the individual and the age that is used as a target to elicit expectations. Thus, Elder (2013) found that older HRS respondents became more "pessimistic" regarding their future survival (i.e., they underestimated their objective survival probabilities), and that respondents in the original HRS cohort (1992) were more "optimistic" (i.e., they overestimated their objective survival probabilities) than the cohort recruited in 2004.

Third, empirical research has also uncovered some important *discrepancies* between subjective expectations and observed experiences. Thus, Hamermesh (1985) showed that individuals underestimate their short-term survival probabilities and overestimate their long-term survival probabilities relative to actuarial life table estimates. Similarly, Elder (2007) found that in the 1992–2004 HRS, the younger respondents (early fifties) were too "pessimistic" about their chances of surviving to young old ages, but that the older respondents (early sixties) were considerably more "optimistic" regarding their chances of surviving to more advanced ages (particularly to age 85 and older) when compared to actuarial estimates ("flatness bias"). A study by Post and Hanewald (2010) found that older individuals were more "optimistic" about their survival prospects (i.e., they overestimated their survival chances), and that, not surprisingly, these subjective expectations translated into more conservative saving behaviors.

Fourth, and finally, it has been suggested many times that subjective survival probabilities are likely to contain information that is not captured by either self-reported health status or objective measures of health limitations (Popham and Mitchell 2007). Hurd and McGarry (2002) found that self-rated health status and subjective survival expectations among individuals aged 46–65 were *independently associated with individual mortality experiences between the first and second HRS waves*, even after accounting for effects of multiple confounders, including socio-demographic characteristics and objective measures of health. This result is corroborated in a study that used information from the first wave of the Assets and Health Dynamics among the Oldest Old (AHEAD) study (individuals aged 70 and older) (Siegel et al. 2003). Additional evidence regarding the unique dimensions tapped by subjective expectations comes from the Australian Longitudinal Study of Aging (ALSA), in which researchers found that individuals' subjective survival expectations and mortality risk estimates were related to parental longevity (van Doorn and Kasl. 1998).

Although the above findings are roughly consistent and recurrent, there are also some salient conflicting results. This should not be surprising in a new research area in which there are unresolved disagreements about concepts, measurements and models, and the utilization of data sources that are not always well harmonized.

In this paper, we examine empirical evidence pertaining to the first (consistency) and fourth (responsiveness to individual health experiences) patterns outlined above. We do so by using strategies that partially circumvent three problems that are commonly encountered: (a) how to define robust models that can translate subjective expectations into standard conditional survival patterns that are comparable to the observed patterns; (b) how to treat "ambiguous" subjective expectations (focal and inconsistent responses); and (c) how to identify formalized protocols for making statistical inferences about the effects of individual traits, behaviors, exogenous changes, and time.

In the following, we address all three problems. First, we formulate robust models that can translate subjective survival expectations into predictions of mortality risks that are comparable to objective mortality rates. These models are flexible and easily estimated, and their relative performance is readily evaluated. Second, we assess the sensitivity of empirical estimates to the treatment of imprecise information; e.g., the ubiquitous and pervasive presence of focal and inconsistent responses. Although all researchers are well aware that if left unresolved, these responses engender problems that could lead to flawed inferences (Bassett and Lumsdaine 2001; Gan et al. 2005; Kuwaja et al. 2007; Lillard and Willis 2001; Lumsdaine and Potter van Loon 2012), not all published work on the subject has investigated the parameter uncertainty these responses could generate. Finally, we use variants of generalized accelerated failure time models to evaluate the impact of individuals' characteristics, behaviors, and experiences with exogenous shocks on the formation of subjective survival expectations.

3 The data

3.1 The health and retirement study

The data used in this study are drawn from the Health and Retirement Study (HRS).[3] The HRS is a longitudinal survey designed to gather information on individuals in the U.S. from pre-retirement into retirement. The first wave's (1992) target population included individuals born between 1931 and 1941 who were living in households, and the spouses or partners of these individuals, regardless of their ages. Out of the 15,497 individuals who were eligible to be interviewed in 1992, 12,654 respondents were actually interviewed. Since then, the individuals in this initial cohort have been re-interviewed every two years. The entire survey consists of five birth cohorts who have been incorporated into the study over time. In the present study, we examine data from the first, fourth, and fifth HRS cohorts. The first cohort is the initial HRS cohort. The fourth cohort, the War Baby (WB) cohort, consists of 2,529 individuals who were born between 1942 and 1947.

[3] For a detailed description of the HRS, refer to: Juster and Suzman (1995).

These respondents were first interviewed in 1998, and every two years thereafter. Finally, the fifth cohort, the Early Baby Boomer (EBB) cohort, consists of 3,340 individuals who were born between 1948 and 1953. These respondents were first interviewed in 2004, and every two years thereafter. Information by racial groups comes from oversamples of Hispanics, blacks, and Florida residents.[4] Finally, the HRS also includes information on the survival status of the respondents, and linked information about decedents from the National Death Index. We use data from the first eight HRS waves (1992–2006). Tables 1 and 2 display the pertinent descriptive statistics for the sample cohorts we use in this paper; namely, respondents who were aged 50 to 61 in 1992 and in 2004.

3.2 Subjective expectations in the HRS

Since 1992, the HRS has included a number of questions designed to elicit respondents' subjective expectations – or, more precisely, subjective probability distributions – regarding a range of future events. In 1992, the questions on subjective survival probabilities were as follows: "Using any number from zero to ten, where '0' equals absolutely no chance and '10' equals absolutely certain... What do you think are the chances that you will live to be 75 or more?" "And how about the chances that you will live to be 85 or more?" From 1994 onward the questions were reworded as follows: "Please answer the questions in terms of percent chance. Percent chance must be a number from 0 to 100, where '0' means there is absolutely no chance, and '100' means that it is absolutely certain." In addition to including this change, the 1994 HRS wave was the first wave that restricted the age at which the first of the above-mentioned questions (survival to age 75) was posed to individuals aged 65 and younger, and the age at which the second question was posed to individuals aged 75 and younger. This format was maintained for the 1996 and 1998 HRS waves. In 2000, the question took on the following format: "How sure are you that you are going to live to be... 75 years or more (if the respondent's age is less than or equal to 65 years); 80 years or more (age 69 years or less); 85 years or more (age between 70 and 74 years); 90 years or more (age between 75 and 79 years); 95 years or more (age is 80 and 84 years); and 100 years or more (age between 85 and 90 years)?" As before, zero represented "Absolutely no chance" and 100 represented "Absolutely certain." The subjective survival questions were not posed to proxies.

4 The present study uses the RAND version of the HRS: RAND HRS Data File Version "H" (http://hrsonline.isr.umich.edu/modules/meta/rand/index.html).

Table 1:
HRS 1992 – Descriptive statistics: Percentage distribution of selected variables

	Educational attainment				Obese	Smoker
	Less than High School	High School	Some college	College and above		
White males						
Including inconsistent answers (N = 3345)	20.33	36.20	20.48	23.00	21.20	27.59
Excluding inconsistent answers (N = 2572)	17.86*	35.71	21.09	25.34*	21.01	26.00
White females						
Including inconsistent answers (N = 3754)	22.91	43.50	19.69	13.91	23.04	25.28
Excluding inconsistent answers (N = 2655)	19.74**	45.58†	20.49	14.20	22.49	25.31
Black males						
Including inconsistent answers (N = 613)	41.44	32.95	16.48	9.14	26.43	38.99
Excluding inconsistent answers (N = 333)	40.84	29.73	18.02	11.41***	28.83	38.44
Black females						
Including inconsistent answers (N = 901)	40.29	32.74	15.76	11.21	42.84	23.53
Excluding inconsistent answers (N = 477)	37.11	34.17	15.30	13.42	43.82	23.90

Note: Answers are defined as inconsistent when P(75) and P(85) satisfy P(75) ≤ P(85).
Statistical Significance: Difference between the two sample proportions, including and excluding inconsistent answers.
$^{\dagger}p < .1$, $^{*}p < .05$; $^{**}p < .01$, $^{***}p < .001$ (two-tailed tests).

Table 2:
HRS 2004 – Descriptive statistics: Percentage distribution of selected variables

	Educational attainment					
	Less than High School	**High School**	**Some college**	**College and above**	**Obese**	**Smoker**
White males						
Including inconsistent answers (N = 3842)	9.63	28.73	27.95	33.68	30.32	22.47
Excluding inconsistent answers (N = 2422)	6.19^{***}	$26.59^{\dagger}$	28.32	38.89^{***}	31.18	21.09
White females						
Including inconsistent answers (N = 5176)	10.55	36.44	27.47	25.54	31.09	19.47
Excluding inconsistent answers (N = 3118)	7.83^{***}	36.44	28.61	27.13	33.29^{*}	19.63
Black males						
Including inconsistent answers (N = 710)	24.51	29.86	27.61	18.03	31.53	37.11
Excluding inconsistent answers (N = 300)	21.33	31.33	29.33	18.00	36.49	34.00
Black females						
Including inconsistent answers (N = 1202)	21.63	33.78	27.79	16.81	52.92	23.33
Excluding inconsistent answers (N = 428)	13.55^{***}	37.85	30.37	18.22	54.76	23.83

Note: Answers are defined as inconsistent when P(75) and P(80) satisfy P(75) ≤ P(80).
Statistical Significance: Difference between the two sample proportions, including and excluding inconsistent answers.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ (two-tailed tests).

Figure 1:
Subjective survival to age 75. Focal responses (0, 50, and 100): percentages by gender and race – HRS 1992

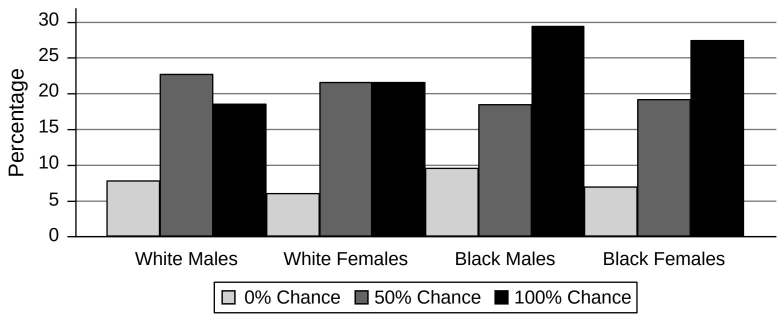
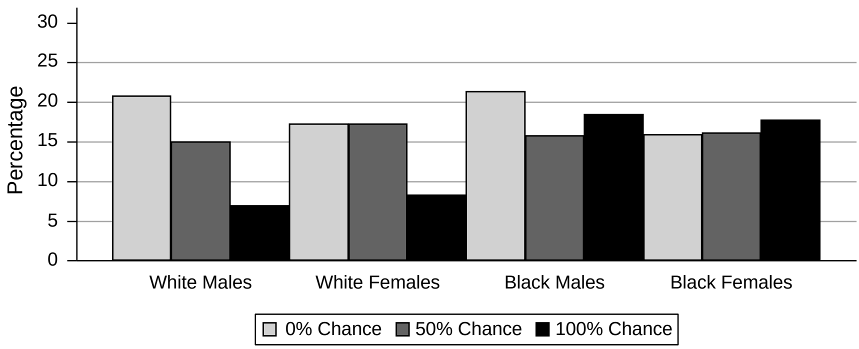


Figure 2:
Subjective survival to age 85. Focal responses (0, 50, and 100): percentages by gender and race – HRS 1992



3.3 Focal and inconsistent responses in the HRS

Of the 9,746 individuals (52.97% of whom were women) aged 50–61 who were interviewed in 1992, 9,049 answered the questions on subjective survival to ages 75 and 85. As of 2006, 1,511 deaths were registered among the individuals in this population, and a total of 828 individuals were lost to follow-up. Statistics summarizing selected variables are in Tables 1 and 2. Figures 1 and 2 show the gender- and race-specific prevalence of focal responses given in 1992 to the questions on subjective survival to ages 75 and 85, respectively.[5] These figures show that focal answers were common. Across all gender and race groups, the heaping on answers reflecting a "0% chance" of surviving ranged from 7.8% to 9.5% for age 75 and from 15.9% to 21.3% for age 85. The heaping on answers reflecting a "50% chance" of surviving ranged from 18.4% to 22.7% for age 75 and from 15.0% to 17.3% for age 85. Finally, the heaping on answers reflecting a "100% chance" of surviving ranged from 18.5% to 29.4% for age 75 and from 6.9% to 18.5% for age 85.

The noise arising from heaping or focal responses was made worse by the inconsistency that occurred when the implied probability of surviving to age 75 was lower or equal to the implied probability of surviving to age 85 (1992 HRS) or to age 80 (2004 HRS). Figure 3 displays the prevalence of the inconsistent responses by gender, by race, and by whether the response was focal (heaped). Unsurprisingly, we find that the largest fraction of inconsistent responses was among the focal answers, and was dominated by cases with an elicited probability of surviving to age 75 that was equal to the elicited probability of surviving to age 85 (or to age 80, depending on the HRS wave). The percentage of inconsistent responses resulting from the elicited probabilities of surviving to age 75 that equaled the elicited probabilities of surviving to age 85 ranged from 17.7% among white males to 33.6% among black males.

Although the educational levels of the individuals who offered inconsistent and/or focal responses differed from those of the individuals who offered consistent and non-focal responses, these differences were small. In particular, the educational distribution among whites with appropriate responses was slightly slanted toward higher educational attainment (see Tables 1 and 2).[6]

4 Models and estimation

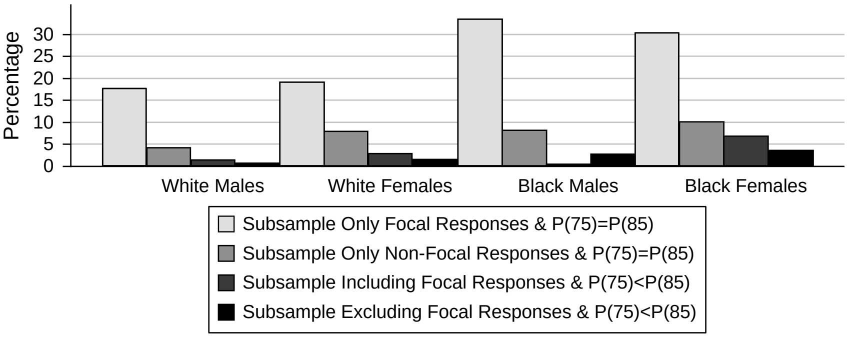
4.1 Translation of subjective expectations into conditional survival probabilities

We use the answers to the 1992 questions eliciting the individual probabilities of surviving from age x to ages 75 and 85. Each individual response is an observation of the (subjective) conditional probability of surviving from age x to ages 75 and 85, $S_x(75)$ and $S_x(85)$. We assume that these observables are synthetic outcomes generated by a latent individual assessment of mortality risks, and that there is intra-individual homogeneity in the assessments, such that the set of pairs ($S_x(75)$,

[5] Figures A.1 and A.2 in the appendix show the gender- and race-specific prevalence of focal responses given in 2004 to the questions on subjective survival to ages 75 and 80, respectively.

[6] Differentials in the focal and the inconsistent responses by birth cohorts, obesity status, and smoking behavior are quite small, and are not shown here.

Figure 3:
Subjective survival to ages 75 and 85. Focal responses (0, 50, and 100): Inconsistent responses percentages by gender and race – HRS 1992



$S_x(85)$) observations is consistent with only one pattern of age-specific mortality risks.[7] We employ four different mortality models, Gompertz, Weibull, logistic, and log-logistic, and estimate the parameters via standard Non-Linear Least Squares routines.[8] We use the same models to represent the actual mortality experiences observed in the HRS sample and in the official U.S life tables. (1992).[9] Figures 4 and 5 show the survival curves for all four functions. The logistic and log-logistic models are the best fits, and even though the Gompertz model does not fit as well, it performs well enough. This is in contrast to the much worse performance of the Weilbull function.

Tables 3 to 6 display the parameters for the Gompertz, logistic, Weibull, and log-logistic models estimated from the observed HRS follow-up mortality experiences and from the subjective survival expectations to ages 75 and 85.[10] The figures in Tables 3 and 4 are computed from the entire sample of respondents who answered questions regarding expectations, whereas the figures in Tables 5 and 6 only employ the sample of *consistent responses (but including focal responses)*. Not surprisingly,

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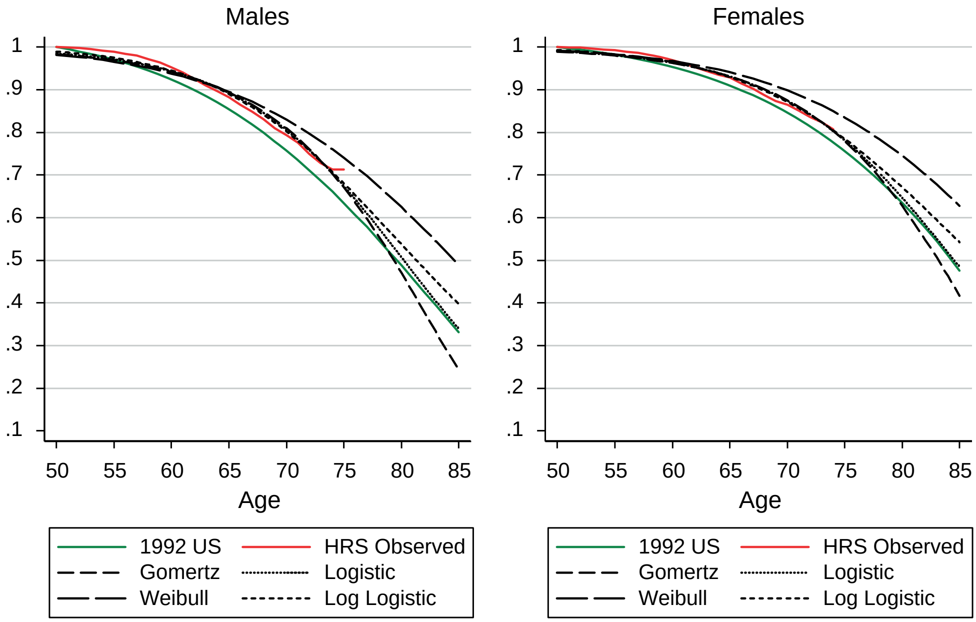
7 This approach is different from those implemented in some previous studies. We use expectations associated with two ages as if they were influenced by a *common assessment of mortality risks*, rather than as two different expressions of different evaluations of the future.

8 When the focal responses were equal to zero or one, we replaced the survival probabilities with 0.001 or 0.999 respectively.

9 In the following we use the HRS observed mortality experiences as a benchmark for comparison. We include comparisons with functions and parameters computed from the U.S. life tables only in some tables and figures. Since, apart from sampling errors, the HRS mortality experiences reproduce the U.S. life tables quite well, the inclusion of all three set of estimates is somewhat redundant.

10 All standard errors are estimated with corrections for clustering, since each individual contributes two observations corresponding to two subjective survival expectations.

Figure 4:
White men's and women's survival functions – U.S. 1992 life tables, Kaplan-Meier, Gompertz, logistic, Weibull, and log-logistic model estimates for the observed 14-year HRS mortality (1992 to 2006)

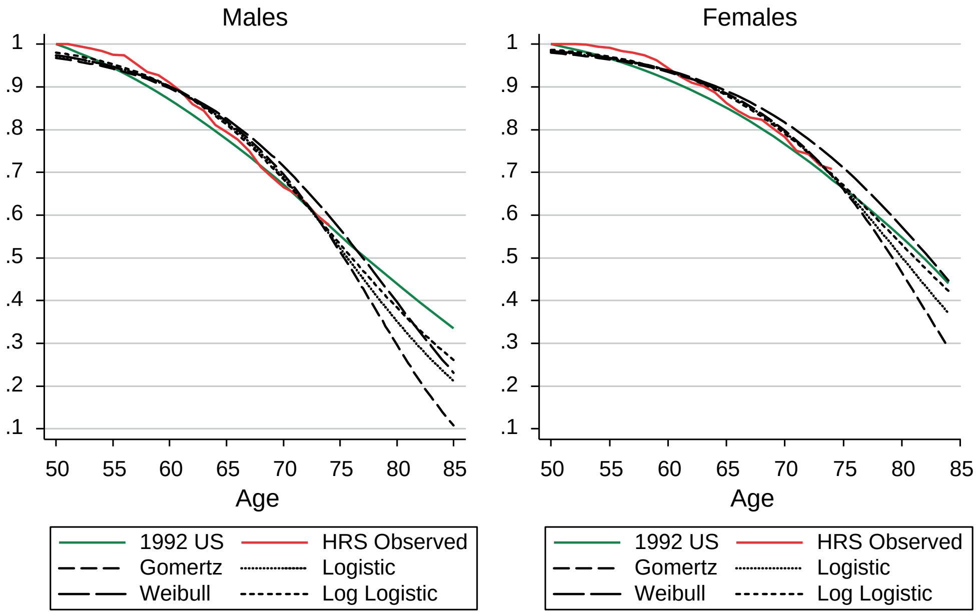


the results suggest that the fit (R^2) of subjective probabilities is better in the more restricted sample. Importantly, however, the tables also show that the parameter estimates based on the *observed experiences* are similar across the two subsamples, which suggests that the *aggregate mortality* experience, at least, is not associated with propensities for inconsistent responses.

In the unrestricted sample (Tables 3 and 4), the main differences between objective and subjective survival are seen in the slope of the mortality curves (the ancillary parameter of the Gompertz, logistic, Weibull, and log-logistic functions): by and large, the age-dependent increase in mortality rates is more than twice as fast in the observed data than in the subjective data. This is because the less exclusionary sample includes pairs of observations $S_x(75)$ and $S_x(85)$ that imply survival curves with implausibly low slopes (due to inconsistent responses). Indeed, at least for the Gompertz and logistic functions, the contrast vanishes when using the more restrictive sample (Tables 5 and 6) that ignores inconsistent responses.

Although the above result may be unsurprising, a warning should be issued: it is not possible to obtain reasonable estimates of mortality parameters from information on subjective survival expectations that includes inconsistent responses. This is important, as it is common practice to use the subjective expectations for

Figure 5:
Black men's and women's survival functions – U.S. 1992 life tables, Kaplan-Meier, Gompertz, logistic, Weibull, and log-logistic model estimates for the observed 14-year HRS mortality (1992 to 2006)



each target age separately, while ignoring the fact that if these expectations are considered jointly, they cannot refer to plausible survival curves.[11]

Figures 6 and 7 show, for each race and gender, the non-parametric Kaplan-Meier survival function for the observed 14-year HRS mortality table (1992 to 2006), the 1992 U.S. mortality life table, and the Gompertz, logistic, Weibull, and log-logistic models fitted to the subjective expectations using the restricted sample. To facilitate comparisons, Tables 7 and 8 in the text display the values of life expectancy at ages 50, 60, and 70 that are *implied* by each of the fitted models in each group, as well as those from the 1992–2006 HRS mortality experiences and the U.S. 1992 life tables.

While the results from the restricted sample in Tables 5 and 6 show that both the Gompertz and the logistic model represent the mortality trajectories observed in the HRS quite well, the predicted Gompertz *survival functions* (not shown) fall off with age much more steeply than the observed trajectories; a limitation that the logistic function does not share. This result, which indicates that the logistic model

[11] The warning applies only if one is interested in contrasting objective and subjective life tables. It is unnecessary if one is investigating the nature of subjective appraisals by themselves.

Table 3:
HRS 1992 – Non-linear regression models: Survival functions – Entire sample of respondents (including focal and inconsistent responses)

	Gompertz				Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	3.75E-06*	0.13***	6.66E-04***	0.07***	80.22***	7.18***	76.84***	11.00***
***N* = 3345**	(1.54E-06)	(0.01)	(1.80E-04)	(3.61E-03)	(0.49)	(0.33)	(0.36)	(0.27)
R^2	0.9996		0.3780		0.9997		0.7375	
Females	2.54E-06*	0.13***	4.06E-04***	0.07***	84.54***	7.49***	79.00***	12.25***
***N* = 3834**	(1.00E-06)	(0.01)	(1.08E-04)	(3.55E03)	(0.66)	(0.35)	(0.37)	(0.33)
R^2	0.9999		0.3327		0.9999		0.7752	
Blacks								
Males	9.33E-06*	0.12***	0.01	0.04**	75.65***	7.12***	73.42***	18.21***
***N* = 623**	(4.01E-06)	(0.01)	(3.89E-03)	(0.01)	(0.39)	(0.35)	(4.17)	(2.55)
R^2	0.9988		0.3203		0.9992		0.7362	
Females	5.43E-06*	0.12***	1.79E-03†	0.05***	80.05***	7.43***	75.14***	18.60***
***N* = 911**	(2.56E-06)	(0.01)	(1.06E-03)	(0.01)	(0.61)	(0.42)	(3.03)	(2.04)
R^2	0.9994		0.2875		0.9995		0.7646	

Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

Table 4:
HRS 1992 – Non-linear regression models: Survival functions – Entire sample of respondents (including focal and inconsistent responses)

	Weibull				Log-Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	1.93E-13	6.95***	1.47E-10	5.69***	0.01***	9.35***	0.01***	7.58***
***N* = 3345**	(1.25E-13)	(0.14)	(1.70E-10)	(0.27)	(4.40E-05)	(0.35)	(4.40E-05)	(0.17)
R^2	0.9991		.3783		0.9998		0.7378	
Females	8.24E-15***	7.58***	3.27E-11	5.99***	0.01***	8.99***	0.01***	6.88***
***N* = 3834**	(1.58E-15)	(0.04)	(3.71E-11)	(0.26)	(0.00)	(0.34)	(4.21E-05)	(0.16)
R^2	0.9994		0.3274		0.9999		0.7756	
Blacks								
Males	2.56E-14***	7.59***	1.31E-06	3.54**	0.01***	9.32***	0.01***	4.90***
***N* = 623**	(4.95E-15)	(0.02)	(4.37E-06)	(0.78)	(6.27E-05)	(0.38)	(3.16E-04)	(0.58)
R^2	0.9987		0.3192		0.9995		0.7363	
Females	1.64E-14***	7.57***	2.29E-08	4.45***	0.01***	9.00***	0.01***	4.85***
***N* = 911**	(3.65E-15)	(0.02)	(5.86E-08)	(0.60)	(9.66E-05)	(0.44)	(2.15E-04)	(0.44)
R^2	0.9992		0.2878		0.9997		0.7647	

Note: Estimates of the level and shape parameters of the Weibull and log-logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]*x*: age; T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ (two-tailed tests).

Table 5:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (including focal and consistent responses only)

	Gompertz				Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	3.39E-06*	0.13***	4.15E-06***	0.13***	81.14***	7.24***	78.60***	7.96***
***N* = 2572**	(1.42E-06)	(0.01)	(6.19E-07)	(0.26E-03)	(0.54)	(0.34)	(0.18)	(0.12)
R^2	0.9997		0.4635		0.9997		0.8123	
Females	1.68E-06*	0.13***	2.59E-06***	0.14***	85.27***	7.30***	80.09***	8.18***
***N* = 2704**	(7.05E-07)	(0.01)	(4.48E-06)	(2.35E-03)	(0.70)	(0.35)	(0.18)	(0.13)
R^2	0.9999		0.4218		0.9999		0.8294	
Blacks								
Males	7.92E-06*	0.12***	1.36E-06*	0.15***	75.41***	6.96***	79.50***	7.52***
***N* = 338**	(3.23E-06)	(0.01)	(6.85E-07)	(0.01)	(0.35)	(0.31)	(0.47)	(0.35)
R^2	0.9990		0.4523		0.9993		0.8075	
Females	5.43E-06***	0.12***	4.28E-06*	0.13***	81.63***	7.67***	79.56***	8.55***
***N* = 483**	(2.88E-06)	(0.01)	(1.90E-06)	(0.01)	(0.81)	(0.51)	(0.46)	(0.37)
R^2	0.9994		0.4285		0.9995		0.8170	

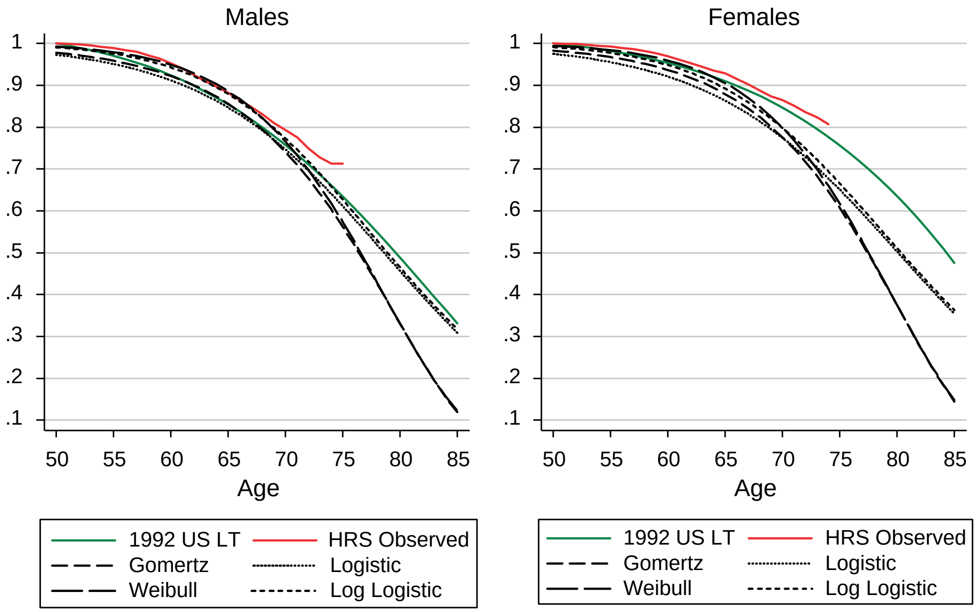
Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures from the HRS follow-up.
[b]x: age; T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

Table 6:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (including focal and consistent responses only)

	Weibull				Log-Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	7.79E-15***	7.67***	6.60E-20	10.64***	1.13E-14*	7.01***	0.01***	10.24***
***N* = 2572**	(1.68E-15)	(0.02)	(4.78E-20)	(0.17)	(4.19E-15)	(0.04)	(2.62E-05)	(0.14)
R^2	0.9984		0.4636		0.9936		0.8126	
Females	8.24E-15***	7.58***	1.17E-20	11.02***	1.70E-14***	6.91***	0.01***	9.98***
***N* = 2704**	(1.42E-15)	(0.02)	(8.87E-21)	(0.18)	(3.89E-15)	(0.03)	(2.56E-05)	(0.14)
R^2	0.9998		0.4219		0.9994		0.8296	
Blacks								
Males	2.35E-14***	7.60***	3.93E-22	11.84***	4.65E-15†	7.30***	0.01***	10.83***
***N* = 338**	(4.39E-15)	(0.02)	(8.70E-22)	(0.52)	(2.71E-15)	(0.03)	(6.91E-05)	(0.47)
R^2	0.9982		0.4524		0.9719		0.8076	
Females	1.57E-14**	0.12***	8.44E-20	10.57***	5.84E-15†	7.17***	(0.01)	9.59***
***N* = 483**	(3.92E-15)	(0.01)	(1.65E-19)	(0.45)	(3.33E-15)	(0.04)	(6.49E-05)	(0.39)
R^2	0.9994		0.4285		0.9940		0.8170	

Note: Estimates of the level and shape parameters of the Weibull and log-logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures from the HRS follow-up data.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

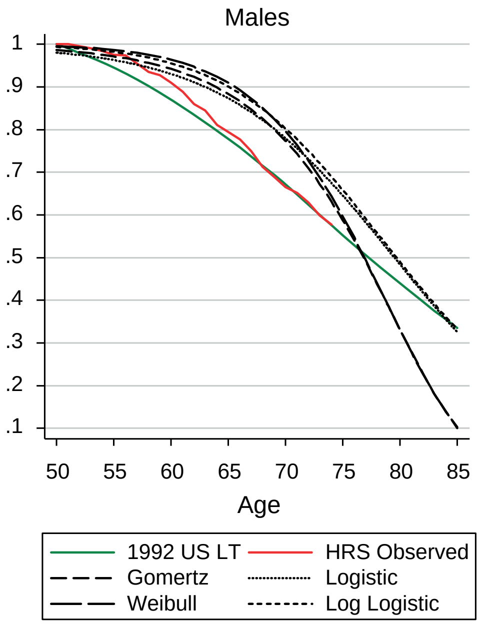
Figure 6:
White men's and women's survival functions – U.S. 1992 life tables, Kaplan-Meier for the observed 14-year HRS mortality (1992 to 2006), and Gompertz, logistic, Weibull, and log-logistic model estimates for subjective survival expectations expressed in 1992 by respondents in the restricted samples



has an edge over the Gompertz model, is in line with recent empirical research on old-age mortality in high-income countries (Horiuchi and Wilmoth 1998; Kannisto et al. 1994; Robine and Vaupel 2001). To ensure consistency with the most recent literature on the subject, we will focus only on the results from the best fitting logistic model.

Tables 7 and 8 reveal three features of the relationship between subjective expectations and experiences of mortality. First, the estimates of life expectancy at ages 50, 60, and 70 from all three sources in all four groups are closely clustered, but the differences between the estimates based on subjective expectations and the HRS and/or the U.S. experiences are slightly larger among white women and black men. Among black men, the subjective expectations yield residual expectancies at age 50 that are 4.0 years higher than the HRS observed life table estimates, whereas the black women's estimates are 2.0 years lower than these values. Among whites, the estimates based on subjective expectations are 2.4 years lower for men and 5.0 years lower for women. Thus, white men and women are "pessimistic," whereas black men are quite "optimistic."

Figure 7:
Black men's and women's survival functions – U.S. 1992 life tables, Kaplan-Meier for the observed 14-year HRS mortality (1992 to 2006), and Gompertz, logistic, Weibull, and log-logistic model estimates for subjective survival expectations expressed in 1992 by respondents in the restricted samples



Second, the tables also suggest that subjective expectations reproduce the observed direction of gender disparities only among whites, and the observed direction of race differentials only among women. Furthermore, when the direction of the differentials from the subjective expectations is the same as the observed differentials, the magnitude of the former is less than half that of the latter.

The magnitude of the differences between the estimates from survival expectations and observed mortality is as large, or slightly larger, than the magnitude of the differences between the mortality experiences from the HRS and from the U.S. life tables.

4.2 Sensitivity of estimates to focal responses

As we showed above, the estimates of life table parameters from subjective expectations are sensitive to the inclusion of inconsistent responses. Moreover, a sample that includes inconsistent responses produces implausible estimates of

Table 7:
Whites – Estimated life expectancies at ages 50, 60, and 70 from Gompertz, logistic, Weibull, and Log-Logistic models (1992 Cohort). Restricted sample

	Age 50		Age 60		Age 70	
	Males	**Females**	**Males**	**Females**	**Males**	**Females**
U.S.	27.1	31.9	19.1	23.2	12.4	15.6
HRS Observed						
Gompertz	28.6	32.3	18.9	22.5	9.9	13.1
Logistic	31.2	35.3	21.5	25.5	12.5	16.1
Weibull	34.8	38.3	25.0	28.5	15.8	19.1
Log-logistic	34.0	39.1	24.2	29.3	15.3	19.9
Subjective						
Gompertz	25.0	26.0	15.4	163	6.9	7.6
Logistic	28.8	30.3	19.3	20.8	10.9	12.2
Weibull	25.6	26.6	15.8	16.7	7.1	7.8
Log-logistic	30.2	31.7	20.4	21.9	11.0	13.1

Note: Source, estimates from Tables 3 to 6. The subjective restricted sample includes focal responses but excludes inconsistent responses.

Table 8:
Blacks – Estimated life expectancies at ages 50, 60, and 70 from Gompertz, logistic, Weibull, and Log-Logistic models (1992 Cohort). Restricted sample

	Age 50		Age 60		Age 70	
	Males	**Females**	**Males**	**Females**	**Males**	**Females**
U.S.	23.0	28.5	16.3	20.8	11.0	14.3
HRS Observed						
Gompertz	23.7	29.0	14.3	19.3	6.1	10.4
Logistic	25.6	31.8	16.1	22.1	8.0	13.2
Weibull	26.5	32.3	17.0	22.6	8.7	13.6
Log-logistic	27.2	34.8	17.7	25.1	9.7	16.2
Subjective						
Gompertz	25.5	25.4	15.8	15.7	7.0	7.3
Logistic	29.6	29.8	20.0	20.4	11.4	12.0
Weibull	26.0	26.0	16.1	16.2	7.1	7.4
Log-logistic	30.8	31.4	21.0	21.7	12.1	12.9

Note: Source, estimates from Tables 3 to 6. The subjective restricted sample includes focal responses but excludes inconsistent responses.

Table 9:
Alternative multivariate logistic models for subjective survival

	M1 (SE)	M2 (SE)	M3 (SE)	M4 (SE)	M5 (SE)	M6 (SE)
Level parameter	79.46 (0.13)***	78.35 (0.16)***	78.87 (0.17)***	77.86 (0.19)***	78.02 (0.50)***	78.97 (0.50) ***
Shape parameter	8.01 (0.08)***	7.56 (0.08)***	8.18 (0.08)***	7.70 (0.20)***	7.70 (0.07)***	7.60 (0.07)***
Gender (1 = Male; 0 = Female)	−1.53 (0.18)***	−1.50 (0.17)***	−1.56 (0.19)***	−1.52 (0.17)***	−1.64 (0.35)***	−1.51 (0.17)***
Race (1 = Black; 0 = White)	−0.22 (0.28)	−0.28 (0.40)	−0.23 (0.29)	−0.28 (0.27)	−0.54 (0.59)	−0.26 (0.34)
Survey (1 = HRS 1992; 0 = HRS 2004)		2.01 (0.18)***		2.01 (0.18)***	1.55 (0.31)***	2.20 (0.18)***
Age group (1 = 50–55; 0 = 56–61)			1.01 (0.19)***	0.85 (0.17)***	0.89 (0.60)**	0.52 (0.17)***
Race* survey					1.05 (0.59)†	
Race* age group					−0.79 (0.53)	
Gender* survey					0.39 (0.37)	
Gender* age group					−0.22 (0.35)	
Survey* age group					0.28 (0.36)	
ADLs (1 = Yes; 0 = No)						−3.24 (0.39)***
Chronic conditions (1 = Yes; 0 = No)						−2.94 (0.19)***
R^2	0.82	0.82	0.82	0.82	0.82	0.83

Note: Pooled HRS 1992 and 2004 samples excluding inconsistent responses – Individuals aged 50–61.
N = 18,976, Clusters = 9,488.
Due to changes in the questions, the inconsistent responses for the 1992 HRS are those that satisfy P(75) ≤ P(85), and the inconsistent responses for the 2004 HRS those that satisfy P(75) ≤ P(80).
†p < .1, *p < .05; **p < .01, ***p < .001 (two-tailed tests).

Table 10:
Alternative multivariate logistic models for subjective survival

	M1 (SE)	M2 (SE)
Level parameter	79.40 (0.52)***	78.08 (0.22)***
Shape parameter	7.49 (0.07)***	7.49 (0.07)***
Gender (1 = Male; 0 = Female)	−1.49 (0.18)***	−1.78 (0.17)***
Race (1 = Black; 0 = White)	0.07 (0.26)	0.48 (0.26)
Smoker (1 = Yes; 0 = No)	−2.69 (0.20)***	−2.04 (0.20)***
Obese (1 = Yes; 0 = No)	−1.63 (0.19)***	−1.32 (0.19)***
Less than HS (1 = Yes; 0 = No)		−1.32 (0.26)***
Some college (1 = Yes; 0 = No)		1.53 (0.22)***
College/more (1 = Yes; 0 = No)		2.80 (0.22)***
Survey (1992 = 1; 2004 = 0)	2.01 (0.18)***	2.67 (0.18)***
R^2	0.82	0.83

Note: Pooled HRS 1992 and 2004 samples excluding inconsistent responses -Individuals aged 50–61.
N = 18,652, Clusters = 9,326.
Due to changes in the questions, the inconsistent responses for the 1992 HRS are those that satisfy P(75) ≤ P(85), and the inconsistent responses for 2004 HRS are those that satisfy P(75) ≤ P(80).
†p < .1, *p < .05, **p < .01; ***p < .001 (two-tailed tests).

mortality. This result is important because it suggests that empirical results based on complete samples are likely to be flawed.

Are estimates equally sensitive to the treatment of focal responses? Although we cannot entirely dismiss focal responses centered on zero (highly pessimistic assessment) or on one (highly optimistic assessment), it appears to be the case that respondents choose these values as a simplified form of expressing the direction of their expectations. Clearly, the integrated force of mortality is neither infinite (pessimistic assessment) nor zero (optimistic assessment). Likewise, it may be the case that some of the individuals who provided focal responses centered on 0.50 used this value as a device to express “neutrality,” and were unaware that their choice implied mortality rates five to 10 times higher than the observed rates. Thus, using focal responses as if they were outcomes of individual computations distorts the intentionality of the responses. Nor can we treat the issue of focal responses as a kind of missing value problem, and then deploy the standard machinery of multiple imputation. Careful researchers attempt to “redistribute” focal responses using various methods, particularly the 0.50 responses (Bassett and Lumsdaine; Bruine de Bruin et al. 2002; Gan et al. 2005; Lumsdaine and van Loon 2012; Manski and Molinari, 2010). The problem is that these methods usually rely on strong, unverifiable assumptions, and leave open the possibility that reallocation could lead to worse distortions than the naïve avoidance of the problem. In the absence of a clear-cut strategy, we opt to compute the boundaries of uncertainty after imposing alternative constraints on the sample used for estimation (see Tables A.1, A.2, A.3,

Table 11:
Updating survival expectations – Linear regression – Dependent Variable: ln(-ln(subjective probability of surviving from age *x* to target age in current wave))

	M1	M2	M3	M4
Health shock (1 = Yes; 0 = No)	0.34 (0.05) ***	0.34 (0.05)***	0.29 (0.06) ***	0.28 (0.06) ***
ln(−ln(Subjective prob. of surviving from age *x* to target age estimated from logistic parameters of 1992 wave))	1.57 (0.05)***	1.57 (0.05)***	1.58 (0.05)***	1.57 (0.05)***
Race (1 = Black; 0 = White)	−0.44 (0.08) ***	−0.47 (0.08) ***	−0.46 (0.08) ***	−0.49 (0.08) ***
Race* health shock	−0.16 (0.13)	−0.16 (0.13)	−0.15 (0.13)	−0.15 (0.13)
Gender (1 = Male; 0 = Female)	−0.06 (0.05)	−0.06 (0.05)	−0.06 (0.05)	−0.06 (0.05)
Gender* health shock	0.01 (0.07)	0.01 (0.07)	0.01 (0.07)	0.01 (0.07)
Obese (1 = Yes; 0 = No)		0.20 (0.05)***		0.22 (0.05)***
Obese* health shock		−0.02 (0.08)		−0.00 (0.08)
Smoker (1 = Yes; 0 = No)			0.30 (0.05)***	0.31 (0.05)***
Smoker* health shock			0.11 (0.08)	0.11 (0.08)
Constant	−0.12 (0.05) **	−0.17(0.05)**	−0.19 (0.05) ***	−0.24 (0.05) ***
R^2	0.043	0.044	0.046	0.048

Note: N = 29,890, Clusters = 5,725.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

A.4, A.5 and A.6 in the appendix). These results suggest that the sensitivity of the parameter estimates to the treatment of focal responses is model-dependent. In general, we find that the estimates of parameters are more sensitive to the exclusion of the 50% response.

To summarize, we find that the patterns of mortality estimated from subjective survival expectations reflect quite accurately the patterns of observed or objective mortality. These subjective expectations deviate from observed patterns to the same extent as independent assessments of objectives mortality, such as those from HRS data and from U.S. life tables, differ from each other. Our results suggest that white men and women of both races tend to underestimate their survival chances, and that black men tend to greatly overestimate their survival chances.

We have argued that extreme care must be exercised with samples that include inconsistent responses, and that the best strategy is to exclude them altogether. Not unexpectedly, we find that alternative treatments of focal responses produce different results, but that the levels of uncertainty surrounding their use are modest. Thus, we suggest that future work on subjective expectations place more emphasis on defining a range for the parameters of interest (instead of point estimates with standard deviations), rather than on the identification of methods for allocating focal responses to "proper" numerical values, which is a rather risky enterprise. This strategy is also consistent with the idea of explicitly accounting for individual uncertainty regarding individual expectations (Willis, 2005).

5 Fine-tuned models for subjective expectations

Do the mortality risks implied by subjective survival expectations behave consistently in more refined analyses? For example, are the expectations of individuals with different behaviors and/or health statuses consistent with objective experiences associated with groups exhibiting the same behaviors or health statuses? Do individuals update their expectations in accordance with past experience; e.g., are they sensitive to individual exogenous shocks? Do younger birth cohorts adjust their expectations to reflect mortality improvements at older ages? To examine these questions, we propose fine-tuning the models formulated above to incorporate covariates.

We showed before that a logistic model fitted to the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$ yields estimates of the (unconditional) survival curve that are quite close to both the survival curve that describes the observed HRS and the U.S. mortality experiences during 1992–2006. We now extend the logistic model to include the effects of covariates. To estimate these models, we assume that individual traits and behaviors modify the level parameter of the logistic function, while the ancillary parameter is invariant throughout.[12]

[12] We thus follow standard practice in the estimation of hazard models.

The "level" parameter reflects the average (underlying) mortality risk, whereas the ancillary parameter reflects the age pattern of mortality risks. The conditional probability of surviving to age y given the respondent's age is x is defined as:

$$S_x(y) = (1 + \exp((y - \eta(g(Z_i)))/\tau))/(1 + \exp((x - \eta(g(Z_i)))/\tau)) \qquad (1)$$

where y is either 75 or 85, $x < y$, Z_i is a vector of characteristics, and $g(.)$ is a functional form that, for simplicity, we define as linear. The hazard function corresponding to this conditional survival is:

$$\mu(v) = (1/\tau) * \exp(((v - \eta(g(Z_i)))/\tau))/(1 + \exp((x - \eta(g(Z_i)))/\tau) \qquad (2)$$

We pool together the initial HRS cohort from 1992 with the HRS refreshment cohort from 2004, and create a dummy variable to distinguish them. This will help us compare two birth cohorts with different experiences. In the younger cohort, the proportions of whites, women, and individuals with at least some college education are statistically larger. Moreover, and as expected, the 1992 cohort includes a statistically larger proportion of current smokers than the 2004 cohort, whereas the prevalence of obesity is significantly higher in the younger than in the older cohort (see Tables 1 and 2). We then use the pooled sample to estimate the effects of the covariates on the parameters of model (1) using the (elicited) survival expectations to age 75 and to age 85 (or 80).[13] The covariates include binary variables for gender, race, HRS wave (1992 versus 2004), age (50–55 versus 56–61), and several interactions.

5.1 The effects of traits and behaviors

Table 9 displays the estimates of five models and the corresponding estimates associated with individual characteristics. Because of scaling, a negative coefficient for a covariate implies higher mortality risks. Model 1 shows statistically significant differences by race and gender: blacks and men had survival expectations reflecting higher mortality risks than whites and women, respectively. Model 2 reveals that the subjective expectations of the 1992 HRS cohort (column 2) implied lower mortality risks than the subjective expectations of the 2004 refreshment cohort. In the same model, the effects of race are downgraded to statistical insignificance. Models 3 and 4 show that the younger HRS cohort had subjective expectations that reflected a mortality pattern with lower mortality risks than those of the older HRS cohort. These effects are large and statistically significant. Finally, Model 5 includes

[13] Estimates of the parameters' standard errors are estimated using clustered corrections since each individual contributes two observations corresponding to the two conditional probabilities Sx(75) and Sx(85 or 80). Estimates were obtained from the restricted samples; that is, from the samples that excluded inconsistent answers but included focal answers.

interaction effects, none of which are found to be strongly ($p < .01$ or even $p < .05$) statistically significant.

Are the effects in Table 9 large enough to matter at all? It can be shown (see the appendix) that an absolute change equal to δ in the value of the logistic scale parameter implies an approximate change of about $-0.0062^{*}\delta$ in the force of mortality around age 70. Thus, for example, the largest coefficient associated with membership in the 1992 cohort (2.01) translates into a mortality risk at around age 70 that is 0.0124 lower than the mortality risk associated with membership in the refreshment cohorts. A difference of this magnitude is equivalent to an upward shift in life expectancy at age 50 of about three years, or about 10 percent of the actual U.S. life expectancy at age 50. The differences associated with race and gender are, respectively, one-tenth and two-thirds as large as the effects associated with cohort membership, whereas the differences associated with age group are about 0.42 as large.

We wish to highlight two findings. Why should the individuals in the younger age group express subjective expectations that imply lower mortality than the individuals in the older age group? The younger individuals' implied life expectancies at age 50 were about 1.3 years higher than those of the older individuals. This result contradicts findings from research using different datasets (Wu et al. 2014). However, since these results were compromised because inferences were drawn using separate responses about different target ages – a practice that we believe should be discouraged – we should downplay the importance of these findings. More significantly, however, this result is inconsistent with the literature on self-reported health status showing that older people tend to report being in better health than their younger counterparts (Jylhä et al. 2001). Unlike models in the literature on health self-reports, our models do not control for indicators of individual health conditions or disability. Thus, this inconsistency could have arisen because the average objective health status among older individuals was worse than the average objective health status among younger individuals. However, this was not shown to be the case. In fact, when we estimated our models while controlling for both self-reported ADL and self-reported chronic conditions, we found that the coefficient for the age dummy continued to be statistically significant and pointed toward a more pessimistic assessment among the older than among the younger age group (see Table 9).

Since the finding is unlikely to be due to cohort effects (see below), we are left with the possibility that subjective survival expectation assessments and self-reported health among older individuals tap into very different dimensions than among younger individuals.[14]

[14] The finding reported here is based on broad, coarse age groups. We chose this approach because we wanted to roughly follow the strategy employed in the extant literature, and not because it is the best strategy available. Thus, while it may be possible to explore different functional forms for age (discrete and continuous), such an approach could flounder because the estimation becomes increasingly fragile as the classification of age groups becomes more fine-grained.

The second noteworthy finding is that members of the original HRS cohort had survival expectations that implied mortality risks associated with higher life expectancy at age 50. The differences are equivalent to shifts of about three years less than in the 2004 refreshment cohort. Why should this be the case? Are the differences between the cohorts in Table 9 due to differences in the prevalence of traits that we are not accounting for?

Table 10 displays estimates of a model that includes controls for additional covariates that could influence survival expectations: namely, education, obesity, and smoking status (current, ever, and never). The inclusion of new control variables does not remove the effects under scrutiny, and the 1992 cohort continued to express subjective expectations implying a more forgiving survival curve. In fact, judging by the magnitude of the coefficient (2.67), it appears that the benefits are even greater than those revealed by Table 9.

The results in Table 10 also demonstrate two additional associations of interest. First, the effects of smoking and obesity status are statistically significant, are properly signed, and are very large. Indeed, the smokers' survival expectations translate into mortality risks at age 70 that are about 0.0167 (2.69*0.0062) higher than those of the non-smokers, a value that differs almost 36% from the average mortality in the population at that age. This finding is nothing short of remarkable, as the estimated observed mortality excess at ages 75–79 due to smoking in the U.S. is close to 25% (National Research Council 2011) The difference is equivalent to smoking-related losses in life expectancy at age 50 of about 3.73 years, or 15% of observed U.S. life expectancy at age 50.

The effects of obesity are more modest, but are still quite large, at about two-thirds the size of the effects due to smoking. These findings are in line with rough estimates of mortality excess due to obesity at ages 50 and older (Ho and Preston 2010).

The second interesting result in Table 10 is the education gradient of subjective survival: the sign of the estimated slope not only reproduces the sign of the observed education mortality slope in the U.S., but its magnitude is close to that of estimates for the U.S. in 2000. The difference in survival between those with a college education or more and those with less than a high school education is equivalent to about three years of life expectancy at age 50 (Palloni and Thomas 2013), whereas Table 10 implies a difference of about 1.4 years.[15] Once again, these differences are not larger than the differences routinely found between alternative estimates from observed data.

[15] The U.S. life table for the college-educated has a life expectancy at age 50 of about 31 years, whereas the life table for individuals with less than a high school education is about 28 years. From Table 10: the estimated difference in the mortality levels between those at the extremes of the education distribution is close to one. This implies a shift in mortality risks of about 0.0062 (see the appendix), which in turn translates into a differences in life expectancy at age 50 of about 1.4 years.

5.2 The effects of shocks: updating survival expectations

With the exception of the cohort effects identified above, subjective and objective survival are in sync with each other. We could also conjecture that individuals not only appraise their survival chances with a relatively high degree of accuracy, but that if they do so, they adjust their appraisals in response to external events. If this is the case, then individual expectations should be subject to significant variability owing to the ebb and flow of exogenous shocks, particularly those that are health-related. To test this conjecture, we adopt a model suitable for estimating the effects of time-dependent events (shocks) on time-dependent survival expectations. The models estimated previously are useful when all of the covariates are fixed, but are cumbersome to estimate and interpret when one or more of these covariates vary over time (including the time-varying effects of a fixed covariate).

We introduce a simplifying assumption that preserves the idea that survival expectations mirror underlying mortality risks that are logistic, but that simultaneously enables us to assess the effects of time-dependent external shocks. We propose the following model:

$$S_{ix}(t, x+k) = [S_x^s(x+k)]^{g(Zi)} \tag{3}$$

where $S_{ix}(t, x+k)$ is the expected conditional probability of surviving from age x to age $x+k$ elicited at time t by individual i who is endowed with a vector of relevant individual characteristics Z_i. This is the standard expression for the survival function of a proportional hazard model where the standard is unknown, and can either be neglected (Cox models) or estimated directly (parametric hazard models). The function $S_x^s(x+k)$ is a standard (reference) survival function, and $g(.)$ is a function that translates the vector of characteristics Z_i into changes in the mortality risks underlying the survival function. We choose as a standard the logistic survival function estimated from the initial HRS cohort in 1992, assume that $g(.)$ is a linear function, and take logs on both sides to obtain

$$\ln(-\ln(S_{ix}(t, x+k)) = \beta Z_i + \ln(\ln S_x^s(x+k)) \tag{4}$$

We choose to identify the standard *ex ante* based on the assumption that we already have sufficient information (contained in the standard) to capture the role of aging alone in the formation of survival expectations. What this information leaves out is precisely what we are interested in: namely, the effects on the levels of expected mortality produced by exogenous health shocks. These effects will be reflected as shifts in estimates of the beta coefficient.

A few caveats are in order. First, a covariate with a positive effect in these models shifts mortality risks upward, and flattens the survival curve. Second, if the model is correct, then the estimate of the slope relative to the double log of the standard survival function should be one. Departures of the slope of the regression line from unity suggest either non-proportional hazards or shifts in the standard mortality patterns embedded in survival expectations. In either case, we can use departures from one as a measure of the realism or the suitability of the model. Third, because we need to have full information about the events unfolding over a long period of time, we focus only on the original 1992 HRS cohort, and follow the trajectory of individual responses regarding wave-specific subjective survival. Finally, the vector Z contains control variables (education, gender, race, smoking, and obesity status) and a time-dependent dummy variable that flags whether the individual experiences a health shock in the preceding interwave periods.[16] For simplicity, we only use a one-wave lag specification; e.g., the survival expectations formed at period t depend on health events that occurred in the interwave period immediately preceding t.

Table 11 shows the most important results. First, the estimate of the slope coefficient is slightly larger than one. This implies that the individuals may be using a mortality pattern that rises more steeply with age than the standard logistic we adopt here. Second, the interwave individual health shocks have effects that are properly signed, are statistically significant, and are quite large. Indeed, an estimated effect of 0.34 in Table 11 translates into a decrease in life expectancy at age 50 of about 1.5 years: that is, individuals who experienced at least one health shock in the preceding interwave period adjusted their mortality expectations by adopting a survival function that implies 1.5 fewer years in residual life expectancy at age 50. Note that these are lower bound effects, since (a) they do not take into account the possibility that a particular health shock could have effects spread across a number of time periods, and not just one; and (b) we do not distinguish between types of health shocks, and therefore assume that their effects are homogeneous, which is a somewhat unrealistic assumption.

Finally, obesity and smoking behave as would be expected: obese individuals and particularly smokers adjusted their survival expectations downward upon experiencing a health shock (the interaction effects of smoking and health shock are positive and significant) to a greater extent than their non-obese or non-smoking peers.

6 Discussion

We highlight two sets of findings, substantive and methodological. The substantive findings can be summarized as follows:

1. The subjective probabilities are quite close to the estimates in the actual life tables, and they preserve the basic observed differentials across subgroups.
2. Whites are more “pessimistic” (their expected survival underestimates observed survival) than blacks, and women are more pessimistic than men.

[16] We define as a health shock a diagnosis of the presence of health conditions that were not present in prior waves, including heart disease, diabetes, cancer, lung diseases, and stroke.

3. There is a large but unexplained difference between individuals in the oldest and in the youngest age groups, as those in the former group underestimate their survival chances more than those in the latter group.
4. There is a surprising and unexplained contrast between the original and the more recent cohorts in the HRS (1992 versus 2004). This contrast does not vanish after controlling for important covariates.
5. The objective, observed differentials between smokers and non-smokers, obese and non-obese individuals, and highly educated and less educated individuals are reflected very well in the subjective expectations of survival.
6. There are very large updating effects that become stronger among individuals exposed to higher risks.

By and large, our results are in agreement with those of the recent literature (Roebuck Bulanda and Zhang 2009; Irby-Shasanmi 2013; Zick et al. 2014). Our model fits as well or better than previous models (Hudomiet and Willis 2012; Ludwig and Zimper 2013); and, in contrast to other studies (Elder 2013), we find that subjective forecasts perform quite well, especially when applied to small subpopulations characterized by particular behaviors (smoking) or traits (obesity, education). Finally, we find that younger individuals tend to be more optimistic that older individuals, and that these differences are not attributable to changes in objective health status.

There are three methodological results of note. First, analyses of subjective expectations should not include inconsistent responses, since they lead to flawed estimates. Although the study of inconsistent responses is a legitimate activity on its own, including these responses in analyses involving comparisons with observed survival will lead the research astray. This note of caution applies to studies that utilize multiple subjective expectations, which usually refer to different ages, as if they were unrelated to each other. Indeed, we believe that findings such as those of Elder (2013) and Hammermesch (1985), which show that there is a "tendency of individuals to understate the likelihood of living to relatively young ages while overstating the likelihood of living to ages beyond 80" (Elder 2013), are artifacts of the data that the exclusion of inconsistent responses would eliminate.

Second, the same note of caution is not applicable to focal responses, since they do not have a large influence on the results. This is demonstrated by our finding that alternative treatments lead to similar results, at least in the HRS and with the class of models we estimated.

Third, we recommend the use of relational models to estimate the effects of multiple covariates. A relational model approach allows for crisp interpretations; can be estimated very easily; offers a platform for rigorous comparisons across disparate datasets; and, finally, provides additional tools for verifying the plausibility and fit of the model to the data.

There is still much work to be done in this area. There are, for example, a host of unexplored relationships involving subjective survival expectations and strategic behaviors like savings, retirement, bequests, exposure to risks, and compliance with medical treatment; all of which could influence policies and programmatic health agendas. For example, why do individuals use subjective survival expectations to make decisions about bequests, labor force participation, and retirement? What is the ripple effect of an exogenous health shock on expectations? Does updating actually translate into behavioral changes, such as adopting a new diet or engaging in more exercise? How do individuals parse information about advances in medical technologies and new discoveries, and how is this information incorporated into their survival expectations? For example, could optimism regarding possible advances in screening and therapies lead individuals to abandon vigilant behavior to such an extent that potential mortality improvements are undermined? Ultimately, if subjective expectations accurately reflect objective mortality conditions, they could be used as complementary indicators when studying SES differentials. The advantage of using this approach is that the data on subjective expectations provide much more detail than is available from the standard sources that are routinely used for the study of mortality differentials.

Finally, understanding the process of the formation of subjective survival expectations could shed light on health and mortality differentials across societies and cultures. Group differentials in the mechanisms that shape individual expectations about mortality risks may tell us a great deal about the pathways that lead to the production of objective heath and mortality differentials.

References

Bassett, W. F. and R. L. Lumsdaine 2001. Probability limits: Are subjective assessments adequately accurate? *The Journal of Human Resources* 36(2): 327–366.

Benítez-Silva, H. and H. Ni 2008. Health status and health dynamics in an empirical model of expected longevity. *Journal of Health Economics* 27(3): 564–584.

Bruine de Bruin, W., P. S. Fischbeck, N. A. Stiber, and B. Fischhoff 2002. What number is ”Fifty-Fifty”?: Redistributing excessive 50% responses in elicited probabilities. *Risk Analysis* 22(4): 713–723.

Elder, T. E. 2007. Subjective Survival Probabilities in the Health and Retirement Study: Systematic Biases and Predictive Validity. MRRC Working Paper WP 2007-159. Michigan Retirement Research Center (MRRC). University of Michigan.

Elder, T. E. 2013. The predictive validity of subjective mortality expectations: evidence from the health and retirement study. *Demography* 50: 569–589.

Falba, T. A. and S. H. Busch 2005. Survival expectations of the obese: Is excess mortality reflected in perceptions? *Obesity Research* 13(4): 754–761.

Gan, L., M. D. Hurd, and D. L. McFadden 2005. Individual subjective survival curves. In *Analyses in the economics of aging*, ed. D A. Wise, 377–402. Chicago: University of Chicago Press.

Hamermesh, D. S. 1985. Expectations, life expectancy, and economic behavior. *The Quarterly Journal of Economics* 100(2): 389–408.

Ho, J. Y. and S. H. Preston 2010. U.S. mortality in an international context: Age variations. *Population and Development Review* 36(4): 749–773.

Horiuchi, S. and J. R. Wilmoth 1998. Deceleration in the age pattern of mortality at older ages. *Demography* 35(4): 391–412.

Hudomiet, P. and R. J. Willis 2012. Estimating Second Order Probability Beliefs from Subjective Survival Data. NBER Working Paper 18258. National Bureau of Economic Research (NBER), Cambridge, MA.

Hurd, M. D., D. McFadden and A. Merrill 1999. Predictors of Mortality among the Elderly. NBER Working Paper 7440. National Bureau of Economic Research (NBER), Cambridge, MA.

Hurd, M. D. and K. McGarry 1995. Evaluation of the subjective probabilities of survival in the health and retirement study. *Journal of Human Resources* 30 (0 Special Issue on the Health and Retirement Study: Data Quality and Early Results): S268–S292.

Hurd, M. D. and K. McGarry 2002. The predictive validity of subjective probabilities of survival. *The Economic Journal* 112: 996–985.

Idler, E. L. and Y. Benyamini 1997. Self-rated health and mortality: A review of twenty-seven community studies. *Journal of Health and Social Behavior* 38: 21–37.

Irby-Shasanmi, A. 2013. Predictors of subjective life expectancy among African American. *Research on Aging* 35: 322–347.

Jylhä, M., J. M. Guralnik, J. Balfour and L. P. Fried 2001. Walking difficulty, walking speed, and age as predictors of self-rated health. *Journal of Gerontology: Medical Sciences* 56A(10): M609–M617.

Juster, F. T. and R. Suzman 1995. An overview of the health and retirement study. *Journal of Human Resources* 3 (Special Issue on the Health and Retirement Study: Data Quality and Early Results): S7–S56.

Kannisto, V., J. Lauritsen, A. R. Thatcher and J. W. Vaupel 1994. Reductions in mortality at advanced ages: Several decades of evidence from 27 countries. Population and Development Review 20: 793–870.

Khwaja, A., F. Sloan and S. Chung 2006. Learning about individual risk and the decision to smoke. *International Journal of Industrial Organization* 24: 683–699.

Khwaja, A., F. Sloan, and S. Chung 2007. The relationship between individual expectations and behaviors: mortality expectations and smoking decisions. *Journal of Risk and Uncertainty* 25: 179–201.

Lillard, L. and R. Willis 2001. Cognition and Wealth: The Importance of Probabilistic Thinking. MRRC Working Paper WP 2001-007. University of Michigan Retirement Research Center (MRRC), Ann Arbor, MI.

Liu, J.-T., M.-W. Tsou and J. Hammit. 2007. Health Information and Subjective Survival Probability: Evidence from Taiwan". NBER Working Paper 12864. NBER Working Paper Series. National Bureau of Economic Research (NBER), Cambridge, MA.

Ludwig, A. and A. Zimper 2012. A parsimonious model of subjective life expectancy. *Theory and Decision* 75(4): 519–541.

Lumsdaine, R. L. and R. J. D. Pooter van Loon 2012. Wall Street vs. Main Street: A Comparison of Views. NBER Working Paper 19103. NBER Working Paper Series. National Bureau of Economic Research (NBER), Cambridge, MA.

Manski, C. F. 2004. Measuring expectations. *Econometrica* 5(9): 1329–1376.

Palloni, A. and J. R. Thomas 2013. Estimation of covariate effects with current status data and differential mortality. *Demography* 50: 521–544.

Peracchi, F. and V. Perotti 2010. Subjective Survival Probabilities and Life Tables: Evidence from Europe. Einaudi Institute for Economics and Finance (EIEF) Working Paper 10/16.

Perozek, M. 2008. Using subjective expectations to forecast longevity: Do survey respondents know something we don't know? *Demography* 45(1): 95–113.

Popham, F. and R. Mitchell 2007. Self-rated life expectancy and lifetime socio-economic position: Cross-sectional analysis of the British household panel survey. *International Journal of Epidemiology* 36: 58–65.

Post, T. and K. Hanewald 2010. Stochastic Mortality, Subjective Survival Expectations, and Individual Saving Behavior. Humboldt University, Berlin, Germany. SFB 649 Discussion Paper 2010-040.

Quesnel–Vallée, A. 2007. Self-rated health: Caught in the crossfire of the quest for 'true' health? *International Journal of Epidemiology* 36: 1161–1164.

Robine, J.-M. and J. W. Vaupel 2001. Supercentenarians: Slower ageing individuals or senile elderly? *Experimental Gerontology* 26(4): 915–930.

Roebuck Bulanda, J. and Z. Zhang 2009. Racial-ethnic differences in subjective survival expectations for the retirement years. *Research on Aging* 31(6): 688–709.

Scott-Sheldon, L. A. J., M. P. Carey, P. A. Vanable and T. E. Senn 2010. Subjective life expectancy and health behaviors among STD clinic patients. *American Journal of Health Behavior* 34(3): 349–361.

Siegel, M., E. H. Bradley and S. V. Kasl 2003. Self-rated life expectancy as a predictor of mortality: Evidence from the HRS and AHEAD Surveys. *Gerontology* 49: 265–271.

Singh-Manoux, A., A. Gueguen, P. Martikainen, J. Ferrie, M. Marmot, and M. Shipley 2007. Self-rated health and mortality: short- and long-term associations in the Whitehall II study. *Psychosomatic Medicine* 69: 138–143.

Smith, K. V., D. H. Taylor, F. A. Sloan, F. Reed Johnson and W. H. Desvousges 2001a. Do smokers respond to health shocks? *The Review of Economics and Statistics* 83(4): 675–687.

Smith, K. V., D. H. Taylor and F. A. Sloan 2001b. Longevity expectations and death: can people predict their own demise? *The American Economic Review* 91(4): 1126–1134.

van Doorn, C. and S. V. Kasl 1998. Can parental longevity and self-rated life expectancy predict mortality among older persons? Results from an Australian cohort. *Journal of Gerontology* 53B(1): S28–S34.

Willis, R. J. 2005. Comment on Gan et al. 2005. Individual subjective survival curves. In *Analyses in the economics of aging*, ed. D. A. Wise, 402–411. Chicago: University of Chicago Press.

Wu, S., R. Stevens and S. Thorp 2014. Die Young or Live Long: Modeling Subjective Survival Probabilities. Paper presented at the American Economic Association annual meeting held in Philadelphia, PA. January 3–5, 2014.

Young, H., E. Grundy, D. O'Reilly and P. Boyle 2010. Self-rated health and mortality in the UK: Results from the first comparative analysis of the England and Wales, Scotland, and Northern Ireland longitudinal studies. Office for National Statistics. *Population Trends* 139: 11–36.

Zick, C. D., K. R. Smith, R. N. Mayer and L. B. Taylor 2014. Family, frailty, and fatal futures? own-health and family-health predictors of subjective life expectancy. *Research on Aging* 36(2): 244–266.

Appendix: Relations between logistic survival function, hazard functions and residual life expectancies

The expressions for the logistic unconditional probability of surviving to age x and instantaneous mortality rate at age x are

$$S(x) = 1/(1 + \exp(x - \tau)/\sigma)$$
$$\mu(x) = (1/\sigma)(1 - S(x))$$

The derivative of the mortality function with respect to τ is $\partial\mu(x)/\partial\tau = -(1/\sigma^2)S(x)(1 - S(x))^2$. We choose an ancillary parameter equal to six, estimate the mortality rate at age 70 (approximately the middle of the range experienced by the original HRS cohort, $\mu(70)$ to be between 0.033 and 0.038, and assign $S(70)$ a value close to that experienced in the U.S. in the year 2000 (between 0.75 and 0.82). We can then approximate the value of the derivative at around 0.0062. Computing the life expectancy at age 50 (the earliest age at which the original cohort was observed) and relating this to changes in $S(70)$ and $\mu(70)$ leads to the following relationship: a change of about 0.010 in mortality above age 50 to a change of about 2.31 years of residual life expectancy at age 50.

Figure A.1:
Subjective survival to age 75. Focal responses (0, 50, and 100): Percentages by gender and race – HRS 2004

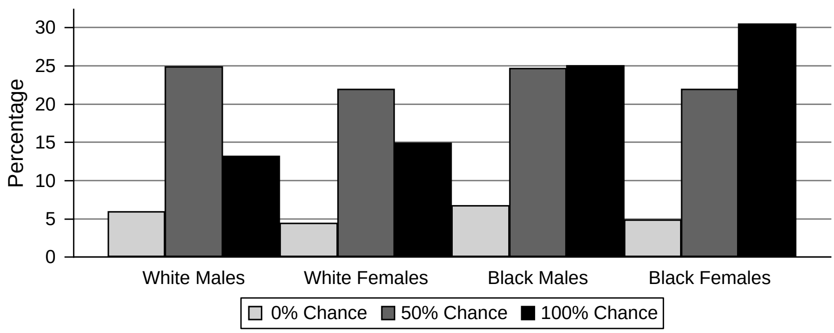


Figure A.2:
Subjective survival to age 80. Focal responses (0, 50, and 100): Percentages by gender and race – HRS 2004

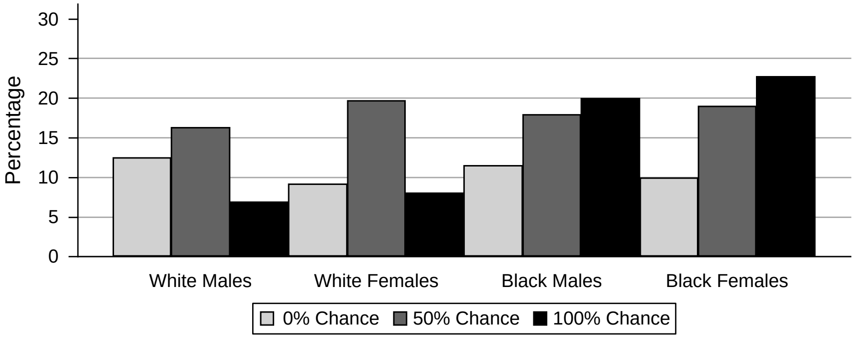


Figure A.3:
Subjective survival to ages 75 and 80. Focal responses (0, 50, and 100): Inconsistent responses percentages by gender and race – HRS 2004

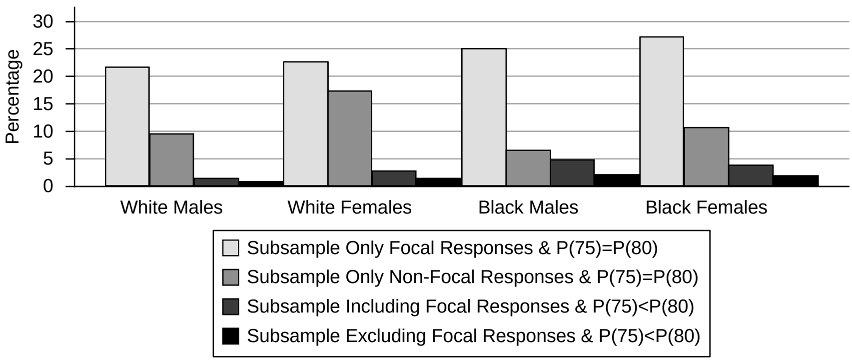


Table A.1:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 50%)

	Gompertz				Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	2.83E-06**	0.13***	4.15E-06***	0.13***	80.47***	7.02***	78. 94***	8.18***
***N* = 1542**	(9.52E-07)	(0.01)	(8.83E-07)	(2.84E-03)	(0.38)	(0.25)	(0.27)	(0.18)
R^2	0.9998		0.4586		0.9998		0.7770	
Females	1.38E-06†	0.13***	1.46E-06***	0.14***	84.52***	7.06***	80.91***	8.22***
***N* = 1653**	(6.76E-07)	(0.01)	(3.31E-07)	(3.01E-0.3)	(0.75)	(0.38)	(0.25)	(0.19)
R^2	0.9999		0.4102		0.9999		0.8041	
Blacks								
Males	1.12E-05*	0.12***	1.07E-06	0.15***	73.99***	6.93***	79.85***	7.41***
***N* = 208**	(4.62E-06)	(0.01)	(7.18E-07)	(0.01)	(0.31)	(0.32)	(0.66)	(0.50)
R^2	0.9986		0.4622		0.9990		0.7716	
Females	8.36E-06†	0.11***	3.12E-06†	0.13***	81.65***	8.00***	80.21***	8.60***
***N* = 306**	(4.78E-06)	(0.01)	(1.81E-06)	(0.01)	(0.93)	(0.61)	(0.65)	(0.54)
R^2	0.9993		0.4233		0.9994		0.7883	

Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the subjective conditional survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ (two-tailed tests).

Table A.2:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 50%)

	Weibull				Log-Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	3.54E-15***	7.81***	5.08E-20	10.72***	0.01***	9.60***	0.01***	9.98***
***N* = 1542**	(8.13E-16)	(0.01)	(4.63E-20)	(0.21)	(5.44E-05)	(0.27)	(3.93E-05)	(0.21)
R^2	0.9959		0.4557		0.9999		0.7772	
Females	1.65E-15†	7.79***	8.63E-22	11.63***	0.01***	9.66***	0.01***	9.93***
***N* = 1643**	(7.94E-16)	(0.03)	(8.37E-22)	(0.22)	(1.09E-04)	(0.45)	(3.67E-05)	(0.21)
R^2	09966		0.4104		0.9999		0.8043	
Blacks								
Males	2.53E-14***	7.63***	8.96E-23	12.20***	0.01***	9.62***	0.01***	10.99***
***N* = 208**	(4.71E-15)	(0.02)	(2.61E-22)	(0.67)	(5.18E-05)	(0.37)	(9.80E-05)	(0.69)
R^2	0.9981		0.4622		0.9994		0.7717	
Females	1.76E-14**	7.56***	1.78E-20	10.94***	0.01***	8.46***	0.01***	9.54***
***N* = 306**	(4.59E-15)	(0.03)	(4.46E-20)	(0.58)	(1.49E-04)	(0.58)	(9.09E-05)	(0.55)
R^2	0.9994		0.4233		0.9995		0.7883	

Note: Estimates of the level and shape parameters of the Weibull and log-logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: target age (75 and 85). Estimated using the NLS fitting of the subjective conditional survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

Table A.3:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 0% and 100% but including 50%)

	Gompertz				Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	3.57E-06*	0.12***	4.15E-06***	0.13***	82.66***	7.49***	78. 60***	7.96***
***N* = 2572**	(1.67E-06)	(0.01)	(6.91E-07)	(2.26E-03)	(0.71)	(0.41)	(0.18)	(0.12)
R^2	0.9997		0.4635		0.9997		0.8230	
Females	2.03E-06*	0.13***	2.59E-06***	0.14***	85.79***	7.48***	80.09***	8.18***
***N* = 2704**	(9.35E-07)	(0.01)	(4.48E-07)	(2.35E-03)	(0.83)	(0.40)	(0.18)	(0.13)
R^2	0.9999		0.4218		0.9999		0.8294	
Blacks								
Males	7.38E-06**	0.12***	1.36E-06*	0.15***	76.17***	7.05***	79.50***	7.52***
***N* = 338**	2.03E-06*	(0.01)	(6.85E-07)	(0.01)	(0.30)	(0.27)	(0.47)	(0.35)
R^2	0.9995		0.4523		0.9996		0.8075	
Females	8.14E-06†	0.11***	4.28E-06*	0.13***	84.04***	8.37***	79.56***	8.55***
***N* = 483**	(4.30E-06)	(0.01)	(1.90E-07)	(0.01)	(1.06)	(0.61)	(0.46)	(0.37)
R^2	0.9995		0.4285		0.9996		0.8170	

Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ (two-tailed tests).

Table A.4:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 0% and 100% but including 50%)

	Weibull				Log-Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	2.05E-14**	7.44***	6.60E-20	10.64***	0.01***	9.01***	0.01***	10.24***
***N* = 2572**	(5.18E-15)	(0.04)	(4.78E-20)	(0.17)	(1.06E-04)	(0.43)	(2.62E-05)	(0.14)
R^2	0.9994		0.4636		0.9998		0.8126	
Females	2.47E-15**	7.77***	1.17E-20	11.02***	0.01***	9.09***	0.01***	9.98***
***N* = 2704**	(8.11E-16)	(0.02)	(8.87E-20)	(0.18)	(1.19E-04)	(0.43)	(2.56E-05)	(0.14)
R^2	0.9986		0.4219		0.9999		0.8296	
Blacks								
Males	1.86E-14***	7.63***	3.93E-22	11.84***	0.01***	9.48***	0.01***	10.83***
***N* = 338**	(2.90E-15)	(0.01)	(8.70E-22)	(0.52)	(5.44E-05)	(0.34)	(6.90E-05)	(0.47)
R^2	0.9982		0.4524		0.9996		0.8076	
Females	7.37E-14*	7.17***	8.44E-20	10.57***	0.01***	8.06***	0.01***	9.59***
***N* = 483**	(3.48E-14)	(0.09)	(1.65E-19)	(0.45)	(1.65E-04)	(0.54)	(6.49E-05)	(0.39)
R^2	0.9996		0.4285		0.9997		0.8170	

Note: Estimates of the level and shape parameters of the Weibull and log-logistic functions. Consistent responses are those that satisfy P(75) > P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

Table A.5:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 0%, 50%, and 100%)

	Gompertz				Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	2.46E-06*	0.13***	4.15E-06***	0.13***	82.10***	7.14***	78.94***	8.18***
***N* = 1542**	(9.11E-07)	(0.01)	(8.83E-07)	(2.84E-03)	(0.49)	(0.29)	(0.27)	(0.18)
R^2	0.9998		0.4556		0.9999		0.7770	
Females	9.00E-07†	0.14***	1.46E-06***	0.14***	83.89***	6.71***	80.91***	8.22***
***N* = 1643**	(5.09E-07)	(0.01)	(3.31E-07)	(3.01E-03)	(0.77)	(0.40)	(0.25)	(0.19)
R^2	0.9998		0.4102		0.9998		0.8041	
Blacks								
Males	1.86E-05**	0.11***	1.07E-06	0.15***	73.82***	7.39***	79.85***	7.41***
***N* = 208**	(6.37E-06)	(0.01)	(7.18E-07)	(0.01)	(0.32)	(0.33)	(0.66)	(0.50)
R^2	0.9988		0.4622		0.9990		0.7716	
Females	1.26E-05	0.11***	3.12E-06†	0.13***	82.79***	8.56***	80.21***	8.60***
***N* = 306**	(8.23E-06)	(0.01)	(1.81E-06)	(0.01)	(1.27)	(0.81)	(0.65)	(0.54)
R^2	0.9991		0.4233		0.9992		0.7883	

Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75)>P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

Table A.6:
HRS 1992 – Non-linear regression models: Survival functions – Restricted sample (consistent responses only, excluding focal responses 0%, 50%, and 100%)

	Weibull				Log-Logistic			
	Observed[a] parameters		Subjective[b] parameters		Observed[a] parameters		Subjective[b] parameters	
	Constant (SE)	Slope (SE)	Constant (SE)[c]	Slope (SE)[c]	Constant (SE)	slope (SE)	Constant (SE)[c]	slope (SE)[c]
Whites								
Males	1.72E-13	6.91***	5.08E-20	10.72***	0.01***	9.49***	0.01***	9.98***
***N* = 1542**	(1.07E-13)	(0.14)	(4.63E-20)	(0.21)	(6.97E-05)	(0.31)	(3.93E-05)	(0.21)
R^2	0.9992		0.4557		0.9999		0.7772	
Females	2.28E-14†	7.27***	8.63E-22	11.63***	0.01***	10.21***	0.01***	9.93***
***N* = 1643**	(1.16E-14)	(0.09)	(8.37E-22)	(0.22)	(1.17E-04)	(0.54)	(3.67E-05)	(0.21)
R^2	0.9986		0.4104		0.9999		0.8043	
Blacks								
Males	7.35E-14***	7.41***	8.96E-23	12.20***	0.01***	8.95***	0.01***	10.99***
***N* = 208**	(1.36E-14)	(0.03)	(2.61E-22)	(0.67)	(5.83E-05)	(0.36)	(9.80E-05)	(0.69)
R^2	0.9991		0.4622		0.9992		0.7717	
Females	2.49E-13	6.91***	1.78E-20	10.94***	0.01***	7.93***	0.01***	9.54***
***N* = 306**	(2.81E-13)	(0.26)	(4.46E-20)	(0.58)	(2.04E-04)	(0.69)	(9.09E-05)	(0.55)
R^2	0.9992		0.4233		0.9993		0.7883	

Note: Estimates of the level and shape parameters of the Gompertz and logistic functions. Consistent responses are those that satisfy P(75)>P(85).
[a]Estimated from the life table constructed from the observed deaths and exposures in the HRS follow-up.
[b]T: Target age (75 and 85). Estimated using the NLS fitting of the conditional subjective survival expectations $S_x(75)$ and $S_x(85)$.
[c]Robust standard errors adjusted for clusters of respondents.
†p < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests).

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Time-to-death patterns in markers of age and dependency

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Abstract

We aim to determine the extent to which variables commonly used to describe health, well-being, and disability in old age vary primarily as a function of years lived (chronological age), years left (thanatological age), or as a function of both. We analyze data from the U.S. Health and Retirement Study to estimate chronological age and time-to-death patterns in 78 such variables. We describe results for the birth cohort 1915–1919 in the final 12 years of life. Our results show that most of the markers used to study well-being in old age vary along both the age and the time-to-death dimensions, but that some markers are exclusively a function of either time to death or chronological age, while other markers display different patterns in men and women.

1 Background

For an individual, age across the life course consists of two components: time since birth, or the *chronological* dimension of age; and time to death, or the *thanatological* dimension of age. In the aggregate, thanatological age is determined by the mortality rate schedule to which a birth cohort is subject until its extinction. Individuals do not know their thanatological age with certainty. To estimate this age, an expectation of

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the lifespan[1] is projected based on scenarios or extrapolations of how mortality rates might change over time. Using this approach, data classified by chronological age, like census population counts, can be reclassified into thanatological age (Brouard 1986).

Prospectively, decreasing mortality is equivalent to moving population into higher thanatological ages, thereby increasing remaining life expectancy (Sanderson and Scherbov 2005). In this case, the notion and the measure of future remaining lifespan is elastic, and is thus subject to uncertainty. In retrospect (after the death of a cohort), the thanatological age structure of a cohort at a given past point in time is a fixed characteristic. Since a closed birth cohort is akin to a stationary population,[2] it may be tempting to assume that because the chronological and the thanatological age structures are symmetrical in stationary populations (Brouard 1989, Vaupel 2009, Villavicencio and Riffe 2016), the patterns of demographic characteristics within cohorts might demonstrate an analogous form of symmetry. This is not so; even in the case of stationary populations or extinct cohorts, the age profiles of other demographic characteristics in the population are decidedly different when viewed chronologically versus thanatologically. If the demographic characteristics in question are states, such as health states, it can be confirmed that for each cohort, the mean duration spent in each state is indeed identical, regardless of whether age is measured chronologically or thanatologically. The cohort expectancies are thus immune to age classification biases. However, distinct patterns emerge in period aggregates due to an interaction between lifespan variation and the age profiles of demographic characteristics.

Some life transitions, states, and changes in state intensities are almost exclusively a function of time to death. When we state that a characteristic is a function of either age perspective we do not imply that age causes the given characteristic to vary, but rather that a characteristic varies in some smooth, regular, or parsimonious way over age. There are other instances in which chronological age captures almost all pertinent variation. In cases in which a characteristic strongly varies as a function of time to death, the common practice of aggregation over chronological age may misrepresent time trends and misguide analyses about change over time and expectations for the future. The measurement of the end-of-life trajectories of characteristics is useful in such cases as a way of separating mortality patterns from patterns in the characteristics themselves. Characteristic measurements are taken while the respondent is alive, but as the thanatological age at each observation is unknown until the date of death is known, it is retrospectively

1 Lifespan is used throughout as a synonym for chronological age at death, or thanatological age at birth. These concepts are identical to the concept of length of life, which is not to be confused with life expectancy, or the mean length of life.

2 The age structure of a birth cohort over time is proportional to the survivorship column of its life table, which is proportional to the stable age structure determined by the Lotka–Euler renewal model when the intrinsic growth rate is equal to zero.

assigned. This final analytical step lends clarity to our understanding of how characteristics vary within and between lifespans.

Incorporating a time-to-death perspective in demographic studies is especially important when assessing the impact of "population aging." To the extent that the health, welfare, and social care demands of a population are functions of the thanatological rather than the chronological age structure, forecasts of the social and economic "costs" of aging that are based on chronological age profiles only are prone to bias (Stearns and Norton 2004).

Research exploring time-to-death patterns has been done in other domains, and the topics examined can be roughly categorized into two types: (1) phenomena that are a function of apparent or perceived time to death (Hamermesh 1985, Hurd and McGarry 1995, Carstensen 2006, Gan et al. 2004, Bìrò 2010, Salm 2010, van Solinge and Henkens 2010, Cocco and Gomes 2012, Payne et al. 2013, Balia 2013), and (2) phenomena that are a function of actual time to death (Miller 2001, Seshamani and Gray 2004, Werblow et al. 2007, Wolf et al. 2015, Stearns and Norton 2004). Research in the first category consists mainly of studies on cognitive transitions and economic or health behaviors, while research in the second category consists mainly of studies on health expenditure, except Wolf et al. (2015), who proposed a model to separate latent time-to-death trajectories of disability. A third branch of research relates the perceived and actual remaining life time (Perozek 2008, Delavande and Rohwedder 2011, Post and Hanewald 2012, Kutlu-Koc and Kalwij 2013). In this paper, we will expand the second group, focusing on a broad range of questions from 10 waves of the U.S. Health and Retirement Study (RAND 2013, HRS 2013).

We aim to understand the end-of-life age patterns of various dimensions of morbidity, as measured by a set of 78 characteristics and indices. To this end, we score the degree to which these characteristics vary in terms of thanatological age, chronological age, or both. In all, we define four different age and lifespan pattern families, which we use to classify the end-of-life prevalence of each characteristic tested. The pattern of variation exhibited by a given characteristic ought to determine how we measure, understand, and respond to the characteristic. We show that while in many cases chronological age ought to be used in conjunction with thanatological age in classifying patterns, chronological age often provides no information at all, and it may even obfuscate true temporal patterns.

Our analytical approach is retrospective rather than prospective, meaning that no life table assumptions are made in the measurement of thanatological age, and no censoring adjustments are necessary. Although more data are available for earlier and later cohorts, we report results only for the cohort born from 1915 to 1919. In the following section, we describe the methods in greater detail. We then demonstrate the four primary age patterns by way of example, and summarize all of the characteristics tested in terms of these four patterns. Finally, we discuss some implications and applications of this work.

2 Data and methods

All of the findings reported in this paper are based on data from the U.S. Health and Retirement Study (HRS).[3] We use version M of the RAND edition of the data, which is conveniently merged across all 10 waves available as of 2013. These data are free to download, and all of the details of data processing and methods are made freely available in an open code repository.[4]

We restrict the sample to individuals who were born between 1900 and 1930 and who died between 1992 and 2011, which narrows the dataset to 37,051 interviews of 9,238 individuals. Of these interviews, 8,137 are from the 1,919 individuals of the 1915-1919 cohort who died. Observations from earlier and later cohorts are kept for the sake of adding information when fitting models to the data.

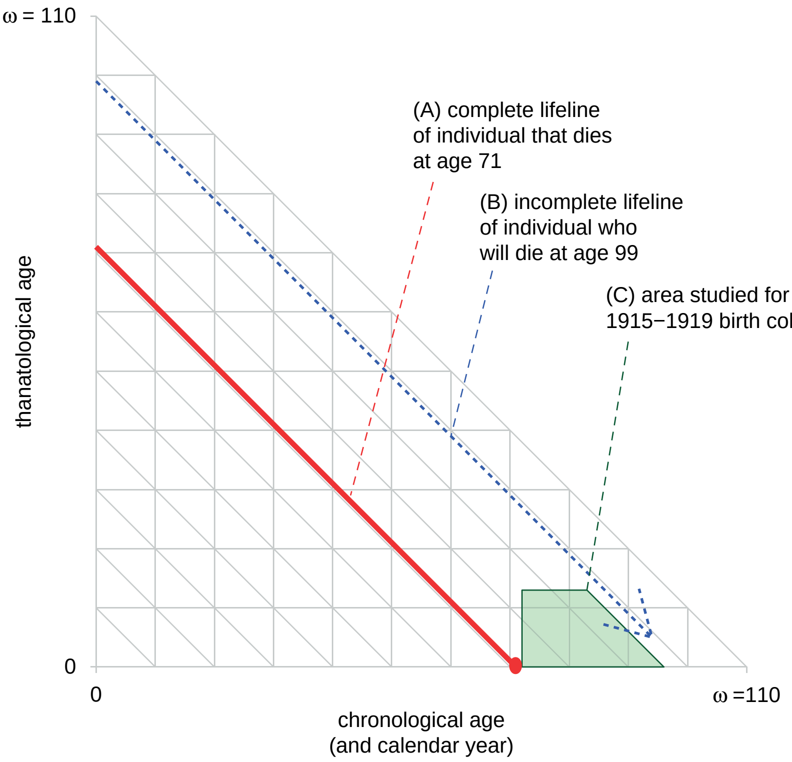
Underpinning this investigation are a series of demographic surfaces indicating the average prevalence of a given marker along chronological and thanatological time axes within a series of quinquennial birth cohorts. However, we focus only on the central 1915–1919 birth cohort. This visual tool is similar to but orthogonal to the familiar Lexis surface. Figure 1 orients the reader by providing the temporal coordinates we use. This diagram represents the various possible lifespans within a given birth cohort, with an arbitrary final age, ω, of 110. One's thanatological age at birth is equal to one's chronological age at death, such that both axes close out with ω. Members of the birth cohort are born on the left side of the diagram, at chronological age zero and with an unknown y coordinate (remaining lifetime) at the time of birth. Lifelines advance downward and to the right, whereby the downward direction indicates the approach to death, and the rightward direction represents both the progression of calendar years and chronological age. The blue arrow (B) indicates a hypothetical lifeline that will eventually expire at age 99, although this property is unknown until death. The present study contains only complete lifelines, such as that depicted in the color red (A) in Figure 1, which completes its lifespan at age 71. In this diagram, diagonal lines represent death cohorts (or lifespan cohorts), as opposed to the birth cohort diagonals found in the standard Lexis diagram.

We limit the current study to the 1915–1919 cohort due to the characteristics of the data source. In the HRS, enough observations are available from the 1915–1919 cohort to allow us to measure the patterns within the area outlined in green (C) in Figure 1. The left bound of this area is chronological age 72, and the diagonal right bound belongs to the completed lifespan of 95. Since the HRS version used spans 20 calendar years (1992–2011), the theoretical upper bound of observation of thanatological age is 20. However, because relatively few individuals in this sample are between thanatological ages 13 and 20 (i.e., individuals who entered the study

[3] The Health and Retirement Study is sponsored by the National Institute on Aging (grant number NIA U01AG009740) and is conducted by the University of Michigan.

[4] This repository includes the R code used to process data, as well as to generate results and figures: https://github.com/timriffe/ThanoEmpirical.

Figure 1:
Chronological age and thanatological age over the life course of a birth cohort



around 1992 and also died around 2011), we study only the thanatological ages that are less than or equal to 12; ergo, the final 12 years of life. As further waves are added to the HRS and the mortality linkage continues, the portion of the life course that may be studied in this way will expand.

The 1915–1919 birth cohort was exposed to the 1918 Spanish influenza epidemic as toddlers (1915–1917 cohorts), as infants (1917–1918 cohorts), and in-utero (1919 cohort). As there is evidence that this exposure manifested itself in various ways in later life (e.g., Almond 2006, Myrskylä et al. 2013), the reader may rightly question whether the results presented here are anomalous. However, the potential anomalous effects from this cohort are "smoothed-out" in our analysis, due both to the breadth of the cohort and to the nature of the statistical method we use to estimate aggregate patterns from individual observations. Specifically, loess smoothing borrows information from observations in earlier and later cohorts. Furthermore, we assume that at these ages other risk factors – some of which are cumulative over the life course – and senescence itself likely drive health patterns to a much greater extent than early-life selection or late-life onsets of poor health due to the Spanish influenza. We also verified that the patterns for this cohort are not visually distinct from those found in earlier and later cohorts. More importantly, our goal here is not to describe the end-of-life experience of this particular birth cohort, but to add resolution to the measurement and description of aging and morbidity indicators, and to contribute to the practice of demography in general.

Age Thanatological age is calculated for each individual as the lag between the interview and the death dates expressed as decimal years. Chronological age is calculated as the lag between the birth and the interview dates in decimal years. Each individual is therefore assigned a chronological and thanatological age at each interview, along with measures of our variables of interest. Since we are interested in viewing characteristics over both chronological age and thanatological age simultaneously, we require observations spread over a wide range of combinations of thanatological and chronological age.

Version M of the RAND HRS dataset runs from 1992 to 2011, which means that each birth cohort is observed over a different range of ages. For example, the 1925–1929 cohort enters observation in 1992 at age 62 at the youngest, and achieves a maximum completed age of 85 by the end of 2011. On the other end, the 1905–1909 enters the HRS in 1992 at age 82 at the youngest, and has a maximum completed lifespan of 105 by the last wave in 2011, albeit with only a few observations at the upper extreme. Results for these and other birth cohorts are also obtained from these data, but portions of these surfaces are based on fewer data points (lifespans > 100) or ages at which labor market exits appear to drive patterns at least as much as senescence (ages < 67, approximately). We focus on the 1915–1919 cohort because the observation window for this cohort is centered on the chronological ages at which most deaths occur, and at which most recent mortality improvements in low-mortality countries have occurred;[5] and because the HRS provides a good density and spread of data points over this window. The lower and upper age bounds vary for questions not available in the first, second, or final waves.

Characteristics We aim for a broad overview of the age variation across different dimensions of old-age disability and well-being. For this reason, we have selected a wide variety of questions from the HRS data. These questions can be roughly grouped into the following categories:

1. Activities of Daily Living (ADL): six items and two composite indices.
2. Instrumental Activities of Daily Living (IADL): seven items and two composite indices.

[5] Own calculations based on UN data (United Nations, Department of Economic and Social Affairs, Population Division 2013). The modal ages at death for the 1915–1919 cohort are 80–81 for males and around 87 for females. These calculations are based on partially observed cohort mortality rates, $M(x)$ (Human Mortality Database 2015).

3. Health behaviors: five items.
4. Functional limitations: six items.
5. Chronic conditions: eight items and one composite index.
6. Cognitive function: 15 items and two composite indices.
7. Psychological well-being: nine items and one composite index.
8. Health care use: 14 items.

The specific variables included in our survey are found in the appendix tables following the same numbering scheme as above. In all, we summarize results from 78 individual and composite items. We exclude variables that were not asked continuously from at least wave 3 through wave 9. Variables that were not available in the first or second wave have left age bounds at ages higher than 72, whereas items that were not asked in wave 10 have upper lifespan bounds that are below 95.

Each survey question must be in a format suitable for numeric operations. This approach entails some compromises in data quality, since some coded responses are less directly quantifiable, and our translation of categorical or ordinal responses to numeric values was at times based on selected cut points. For example, respondents were asked if they felt depressed. We assigned a value of zero to "no" answers and a value of one to "yes" answers. As an example of ordinate recoding, self-reported health had the possible responses "excellent," "very good," "good," "fair," and "poor;" to which we assigned values of zero, zero, zero, one, and one, respectively. Thus, for this kind of variable, population means can be interpreted as prevalences.

Variables with compact or bounded numeric responses were rescaled to range from zero to one. Variables with no clear bounds or very large upper bounds, such as body mass index or number of hospital visits, were not rescaled. These rescalings are intended to simplify the visual interpretation of surfaces as a diagnostic, and they do not alter the quantitative summary measures we use later. Some response sets for particular questionnaire items changed between waves. In these cases, we attempted to assign numerical codes that were consistent over the transition. These recodes are imprecise, but they are good enough for the purposes of this study. In other words, the surfaces we present are not exact measurements, but are meant to provide *impressions* of how characteristics change over age.[6]

Weighting The population universe of the HRS and this study is the resident population of the United States. Therefore, person weights are needed in order to estimate population-level means. One difficulty that arises when using the HRS is that the institutionalized population is treated as a second target population. In all waves but 5 and 6, there are no person-weights assigned to individuals living in institutions. We try to impute missing person-weights according to some simple assumptions. If the individual was assigned a weight in a previous wave, we carry

[6] The pre-processing of variables is full of details that would clutter this paper. Rather than providing a lengthy and detailed appendix describing the case-by-case treatment of variables, we refer readers to the annotated code in the open repository.

this weight over as a constant, unless there was also a non-zero weight in a future interview, in which case we assign the weight according to a within-individual linear pattern. Individuals and interviews that still have missing person-weights after this procedure are discarded from our study. Person-weights compensate for minor detectable attrition in the HRS (Kapteyn et al. 2006), which for our purposes may be considered unbiased.[7]

Loess smoothing Direct tabulations of the weighted data are legible if all of the birth cohorts are combined, but doing this distorts the results due to cohort composition bias. To overcome the birth cohort heterogeneity within surfaces, we use birth cohorts as a third time dimension. As tabulations within this three-dimensional space are noisy, we enhance surface legibility by using a non-parametric local smoother. We specify a loess model of the given characteristic over chronological age, thanatological age, and quinquennial birth cohorts using all of the observations of since-deceased individuals from the 1900 through the 1934 birth cohorts. We fit the model using the loess() function in base R (Cleveland et al. 1992, R Core Team 2013)[8] to the weighted individual-level data for each sex separately, and then predict a surface for the 1915–1919 birth cohort within the study area outlined in green (C) in Figure 1. Weighting is therefore explicit by person-weights, and implicit by point density within the three temporal dimensions.[9]

3 Results

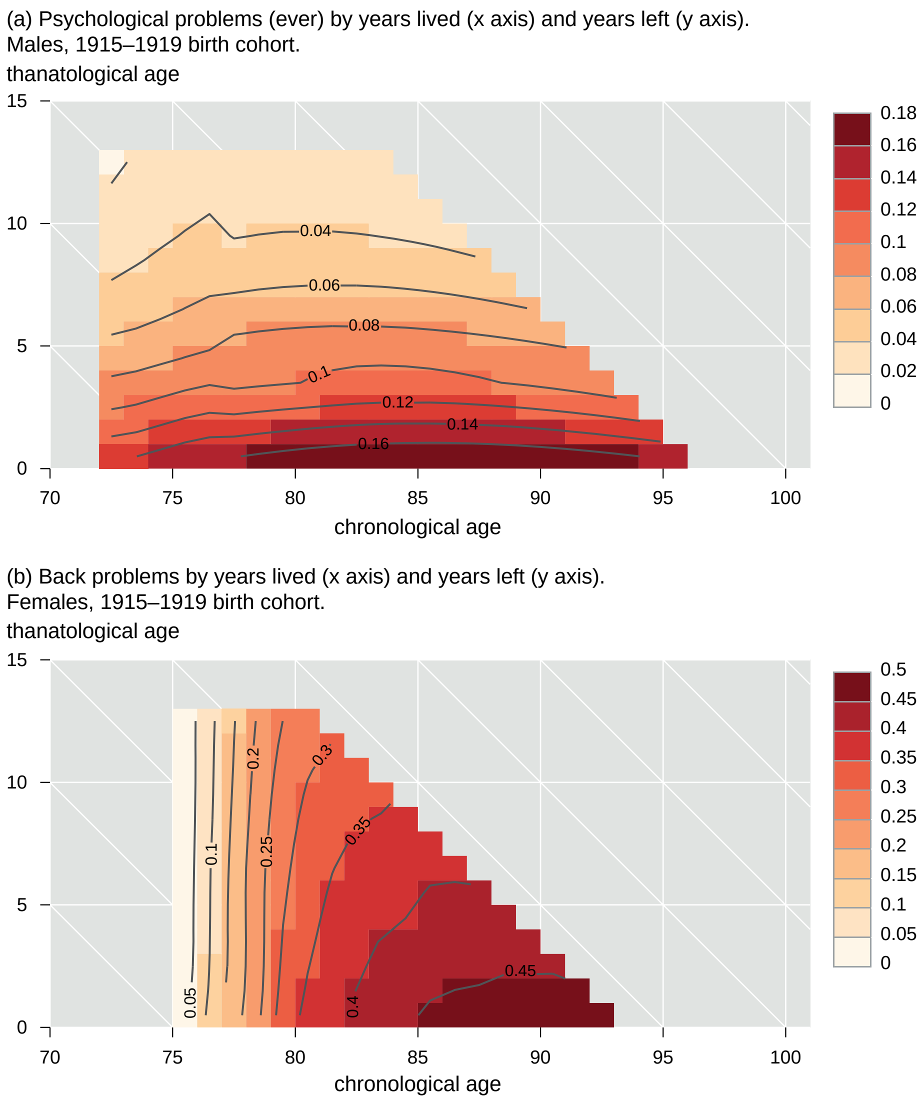
We first present examples of four surfaces that exemplify the major ways in which characteristics tend to vary temporally over the lifespan within a birth cohort. These four major patterns of variation provide a way to categorize and understand markers

[7] Small biases in the survey only appear with respect to baseline characteristics that we do not consider. Attrition due to health conditions, such as mental impairment, is mostly mitigated due to the use of proxy respondents in such situations (Weir et al. 2011).

[8] Using the fitted model, surfaces are produced using the related loess prediction function, predict.loess(). The smoothing parameter, spar, is set to 0.7 for the results we present in the paper. All of the results were also produced using smoothing parameters of .5 and .9, and we concluded that the specific choice of smoothness does not drive results. In order to preserve year units, the three predictor dimensions are not normalized.

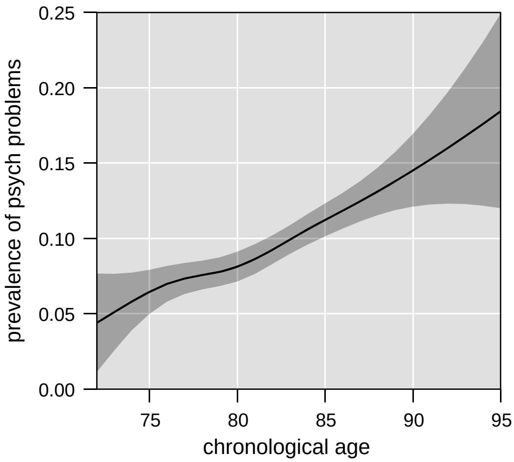
[9] Note that smoothing over these three particular time dimensions is not an overidentification. Within a cohort, smoothing over thanatological age, chronological age, and completed lifespan would be an overidentification, a problem that is similar to the familiar APC problem. The full set of lifespan indices the demographer has to choose from are: birth cohort, death cohort, chronological age, thanatological age, complete lifespan, and period. Within this set of six lifespan dimensions, some combinations invoke overidentification, while others do not. For instance, it would be possible in this case to smooth over years lived, years left, and period, but birth cohorts are the more meaningful category for this study.

Figure 2:
Examples of characteristics that vary along the thanatological and chronological age axes



of aging. We summarize the results of our set of 78 characteristics by calculating Pearson correlation coefficients for each of these four axes, and display the results graphically, as well as in an appendix shaded table.

Figure 3:
Psychological problems (ever) by chronological age only. Males, 1915–1919 birth cohort. With 95% confidence bands from loess fit

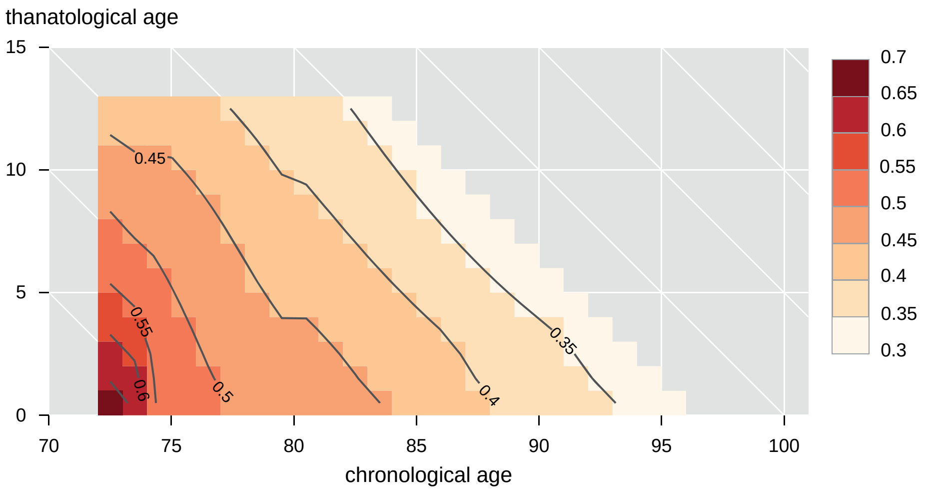


Four major surface axes In most situations, it is obvious to the eye whether a variable operates over thanatological age or over chronological age. There are, however, many instances in which both are at play, or the relationship is complex. We first present surfaces representing psychological problems for men (Figure 2(a)) and back pain for women (Figure 2(b)). These two surfaces are examples of thanatological and chronological characteristics, respectively.

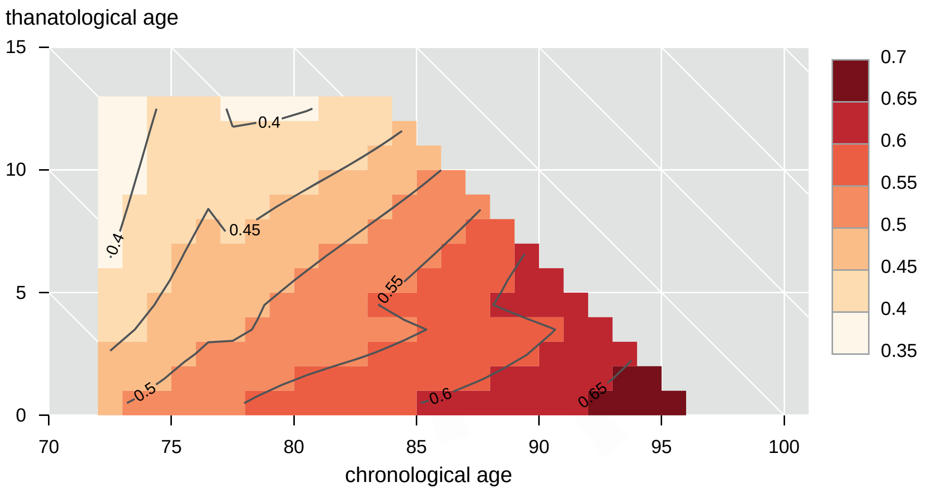
From the direction of the contours on the surface in Figure 2(a), we conclude that the chances of ever having been diagnosed with psychological problems increases with the approach to death, and not with the advancing of chronological age, at least in the window of observation studied here. However, since the risk of death itself also increases according to an approximate exponential pattern at these same ages, aggregating individual results by chronological age produces an increasing pattern over age for this same characteristic (see Figure 3). In this case, the apparent chronological age pattern is due to an interaction between the thanatological pattern seen in Figure 2(a) and the age pattern of mortality itself. We argue that it is imprecise to consider chronological age a risk factor for characteristics that display such strong thanatological patterns, as an apparent chronological age pattern along said margin is a deceptive artifact. Instead, such characteristics appear to operate primarily as effects of the body shutting down, or possibly as a signal that, on average, death is not far off. Thus, these characteristics represent a demographic corroboration of substantive findings in the psychology literature (Carstensen 2006). Ceteris paribum, mortality itself ought to be a good proxy for characteristics that are

Figure 4:
Examples of characteristics that vary by lifespan only or by thanatological age within the lifespan

(a) Smoking (ever) by years lived (x axis) and years left (y axis). Females, 1915–1919 birth cohort.



(b) Blood pressure by years lived (x axis) and years left (y axis). Males, 1915–1919 birth cohort.



highly thanatological. Some of the characteristics studied here display patterns that are strongly thanatological.

Figure 2(b) tells the opposite story about back pain for women. Back pain is a function of chronological age, at least at the population level, until around chronological age 85. This is the dominant way of thinking about most aspects of the aging process. At these ages, back problems provide no information about remaining years of life. Of the characteristics included in this study, only current smoking, arthritis, and self-reports of current versus former memory exhibit such clear chronological patterns (for both men and women).

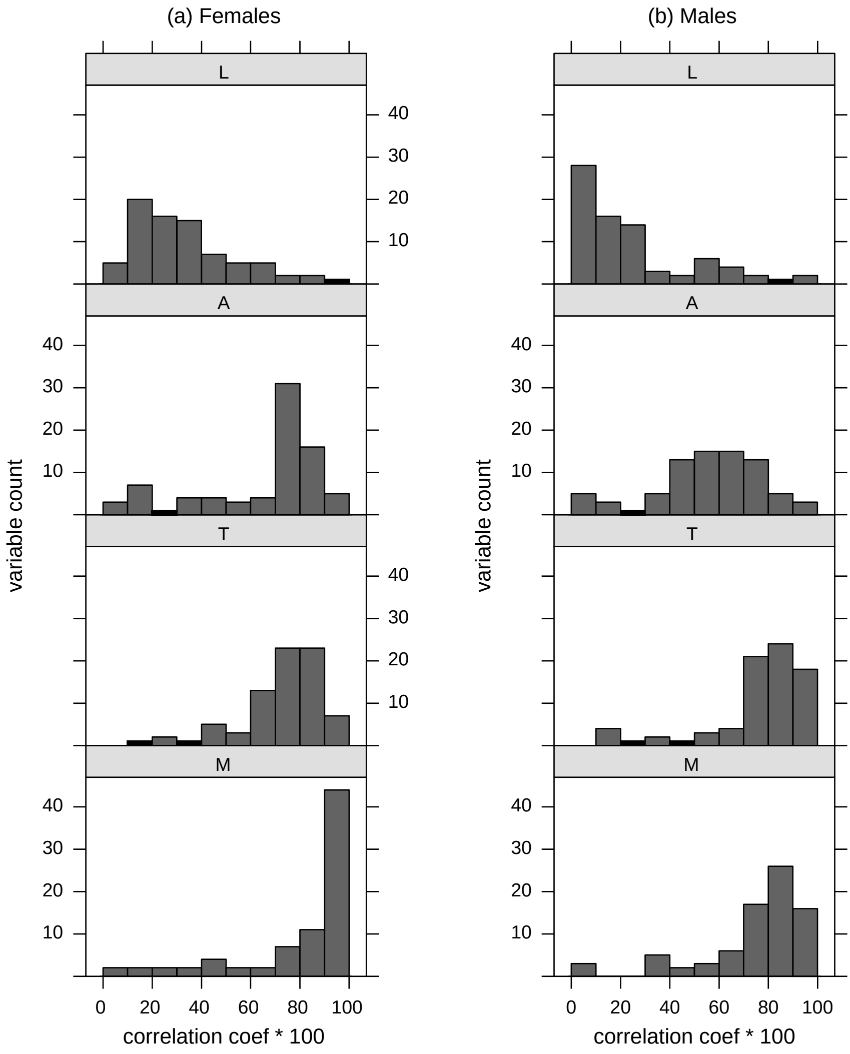
There are other informative patterns among the set of characteristics studied. These include characteristics that vary by lifespan, which display downward diagonal contours in surface plots. Characteristics that vary by lifespan appear to be constant within lifespans, and are often characteristics that *determine* lifespan. Having ever smoked displays such a pattern, as seen in Figure 4(a) for women of the 1915–1919 cohort. This pattern is also a corroboration of science and common sense: smoking kills eventually (at least in this range of lifespans). Other variables that display similar patterns in this window of the lifespan include lung disease among men (this is largely redundant with the former), dental visits in the previous two years among women, and diabetes among women. Sometimes such patterns combine in complex ways that are worthy of further study.

The fourth major pattern of contour variation runs perpendicular to lifelines. One characteristic that clearly displays this pattern is having ever been diagnosed with high blood pressure among men. This characteristic varies by lifespan, and by thanatological age within the lifespan for this window of study. In other words, individuals with longer lifespans display later onset but greater eventual odds of having been diagnosed with high blood pressure. Arithmetically, *chronological age – thanatological age* is the operative predictor of blood pressure. For example, for such characteristics, the condition of a 70-year-old with five remaining years of life may resemble that of an 80-year-old with 15 remaining years of life. On their own, such characteristics are not very useful for predicting eventual lifespan.[10] Some characteristics appear to follow this pattern, albeit with contour lines at angles less than 45°, which may suggest that thanatological morbidity prevalence is somehow *proportional* to length of life. We do not measure this possibility explicitly.

Summary of the results for all characteristics We produce surfaces such as those in Figures 2 and 4 for all 78 variables and each sex. We distill each of these surfaces into four Pearson correlation coefficients, each of which is designed to capture the variation along each of the four major patterns explained above. We call the four patterns thanatological age (T), chronological age (A), lifespan (A + T) (L), and mixed (A – T) (M). Most of the characteristics are well-summarized by either one or two of these patterns. Figure 5 shows the correlation coefficients of all 78 variables binned into count histograms for each sex and major variation pattern separately. This view is meant to provide an impression of how common each major pattern of variation might be in commonly measured characteristics. This statistic

[10] We do not have enough expertise to comment further on blood pressure, but instead only provide an interpretation of the surface presented.

Figure 5:
Distribution of correlation coefficients for each of the four major patterns of variation, all 78 variables examined. L indicates lifespan variation (like Figure 4(a)), A indicates chronological age (like Figure 2(b)), T indicates thanatological age (like Figure 2(a)), and M indicates the mixed type variation (like Figure 4(b))



only captures the rough direction of variation in characteristics, and does not capture differences in levels or gradient steepness.

The first row of this panel shows that variation by lifespan is weak for most variables, and strong for only a few variables (having ever smoked, and having visited a dentist for women). The second row shows that chronological age is indeed an important aspect of variation for many, but not all characteristics (e.g., having ever been diagnosed with psychological problems); and that chronological variation is often stronger among women than among men. The third row shows that thanatological age is an important pattern of variation for many variables: the lower tail is thinner than the tail of chronological age, and there are more cases of strong correlations ($r > 0.80$) in the direction of thanatological variation than of chronological variation. In the distributions over these variables, men tend to show stronger thanatological age patterns than women, and women tend to show stronger chronological age patterns than men. Finally, the most common pattern in these data are for characteristics to vary strongly as chronological age increases *and* as thanatological age decreases, M (especially for many ADLs, IADLs, functional limitations, and many variables of cognitive function). For women, this is very clearly the dominant pattern among the variables studied. For men, the pattern of variation between characteristics is similar to that of thanatological age. In most cases, for variables with strong patterns of variation in the M direction, there are also strong correlations in the A and/or T directions. Of these, M is most commonly paired with T. Characteristics that show strong correlations in both M and T display surfaces with contour lines slanted less than 45°. A more detailed table of the correlation results by variable, pattern, and sex is given in the appendix.

4 Discussion

The distribution of the tested characteristics with respect to the four primary patterns of variation is striking. Chronological age describes the prevalence patterns for many conditions quite well, but the time-to-death patterns are more prevalent among the measures tested. For measures that vary both with the increase in age and the approach to death, the approach to death tends to be the stronger of the two measures. Only a few characteristics vary by length of life, and their patterns are clear. The upshot, as illustrated by comparing Figures 2(a) and 3, is that representing morbidity or disability variables as chronological age patterns can in many or in most cases be misleading as a model of morbidity prevalence, and be biased as a basis for prediction.

These empirical findings must be tempered by noting that (1) the summary measure (correlation coefficient) used here blends out some information, (2) these results may not extrapolate to the set of all testable questions in the HRS, and (3) this relationship does not necessarily hold in other windows of the lifespan or for other birth cohorts. Comparable results for other five-year birth cohorts in the HRS (1905–1925) are given in the manuscript repository.

Furthermore, the patterns presented here are valid for the whole population (of a given sex) taken together, but if the target population was, for instance, broken down by causes of death, the patterns may change. For example, imagine hypothetically that the strong thanatological patterns shown in Figure 2 (psychological problems) were driven by strong patterns within individuals who eventually died of suicide, but that other causes of death displayed entirely different patterns with respect to psychological problems. Such cases are easily imaginable for other characteristics and causes of death. At the time of this research, we did not have access to cause-of-death information from the HRS mortality follow-up. For detailed investigations of particular characteristics, cause-conditioning surfaces would clearly be useful in disentangling morbidity processes, both for the purposes of understanding these processes, and for making cause- and time-of-death predictions.

Research seeking to better document the multidimensional age variation of particular characteristics would benefit from more empirical evidence and further model development. Despite the limitations of this study, we have been able to demonstrate the complex variety of age and lifespan dimensions over which some key aspects of the aging process unfold. All of the indicators we tested are commonly used to describe population aging, and very few of them are exclusively a function of chronological age. If this finding is sustained in other cohorts and populations, and if other indicators that were untested here are also shown to display similar temporal complexity, we submit that the common discourse and debate on the nature and impacts of aging would be better informed through the inclusion of more judicious measurements and descriptions framed in terms of thanatological as well as chronological age. This approach would contribute to the scientific understanding of health and disability processes, and would improve the actuarial accuracy of morbidity projections and of any policies that rely on accurate morbidity projections.

The claim that accounting for time-to-death in predictions of health care expenditure reduces bias has already been established in the health economics literature (e.g., Stearns and Norton 2004). A common finding in health care expenditure predictions is that in times of mortality improvements, predictions based on chronological age patterns of health care expenditure (Sullivan-style predictions (Sullivan 1971)) tend to overestimate total expenditure (e.g., Geue et al. 2014). Since the patterns of variation among the morbidity dimensions we study are similar to those of health care expenditure over chronological age and time-to-death, we here infer that Sullivan-style predictions of morbidity are biased in the same direction.[11] The consequences of overestimating future morbidity prevalence are complex and varied, ranging from budget misallocations, to poor design of social health care systems for the elderly, to lowered expectations regarding the benefits of lengthening life.

We hope that the conceptual model of the life course presented here, which complements the Lexis diagram, will be of use to demographers, public health researchers, and epidemiologists. Other combinations of lifespan time dimensions are also possible, and these would highlight different patterns in the data (Riffe et al. 2017). Given the variety and the availability of such options – which

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[11] Other work in progress treats this point in greater detail (van Raalte and Riffe 2016).

are perhaps now placed in starker relief – a more nuanced understanding of the temporal accounting that relates demographic time perspectives is needed. Further exploration and experimentation with these formal demographic concepts will lead to the development of a more precise toolkit for demographic measurement and the practice of demography, and, ultimately, to more astute contributions to the discourse on population aging.

We suggest a selection of extensions to the exploration carried out here. The present type of analysis must be replicated for more cohorts and populations. A few countries with long-running and fully linked population registers already preside over such information, and we encourage using such data to engage in a more thorough exploration of the temporal richness of population change and population characteristics. The administrators of large-scale panel studies may be motivated to implement, increase, or improve the quality of mortality follow-up modules. Information on the full age dimensions of health outcomes will be valuable. The good news is that many unlinked panel studies may be retrospectively linked to death registers.

If compared over calendar time, demographic work such as this will provide a more precise answer to the question of morbidity compression. Given the chronological-age ruse exemplified in the case of psychological problems (see Figures 3 versus 2(a)), it is safe to say that unless retrospective thanatological measurements of morbidity dimensions are undertaken, we will not have direct information about the shape of the morbidity burden in the final years of life. Using the techniques shown here, researchers may directly estimate the varieties of end-of-life profiles often seen in the literature on morbidity compression (e.g., Fries et al. 2011).

There are also consequences for the popular understanding of aging. By using analyses oriented toward the life course diagram, health care providers can better situate the association of certain health outcomes within stages of the aging process. This is both a question of the allocation of resources and a question of how individuals conceive of themselves with respect to age. We therefore add to the chorus of researchers working to change the measurement of age to reflect the changing experience of age (see, e.g., Sanderson and Scherbov 2013).

The life course surfaces underlying this study highlight important sex differences in the aggregate onset and the trajectory of some aspects of morbidity. Some of these results may corroborate extant findings, such as results on the male-female health-survival paradox, while others may provide us with a new understanding of sexual dimorphism in morbidity. Specifically, it has been shown that women live longer, but in worse health than men (e.g., Case and Paxson 2005), and that this pattern is consistent with evidence indicating that health patterns vary chronologically more among females than among males. In general, these methods and measurements can be used to describe any between-group disparity in demographic or social outcomes, especially those that directly or indirectly relate to remaining years of life. Numerous other avenues of potential investigation may also be devised from the present work. It is our hope that these results are strongly suggestive, and help to orient future investigation.

Acknowledgements

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References

Almond, D. 2006. Is the 1918 influenza pandemic over? long-term effects of in utero influenza exposure in the post-1940 us population. *Journal of Political Economy* 114(4): 672–712.

Balia, S. 2013. Survival expectations, subjective health and smoking: evidence from share. *Empirical Economics* 47: 1–28.

Bìrò, A. 2010. Subjective mortality hazard shocks and the adjustment of consumption expenditures. *Journal of Population Economics* 26: 1–30.

Brouard, N. 1986. Structure et dynamique des populations. la pyramide des anńees à vivre, aspects nationaux et exemples régionaux. *Espace, Populations, Sociétés* 4(2): 157–168.

Brouard, N. 1989. *Mouvements et mod‘eles de population*. Institut de formation et de recherche démographiques.

Carstensen, L. L. 2006. The influence of a sense of time on human development. *Science* 312(5782): 1913–1915.

Case, A. and C. Paxson 2005. Sex differences in morbidity and mortality. *Demography* 42(2): 189–214.

Cleveland, W. S., E. Grosse and W. M. Shyu 1992. Local regression models. *Statistical models in S* 309–376.

Cocco, J. F. and F. J. Gomes 2012. Longevity risk, retirement savings, and financial innovation. *Journal of Financial Economics* 103(3): 507–529.

Delavande, A. and S. Rohwedder 2011. Differential survival in Europe and the united states: Estimates based on subjective probabilities of survival. *Demography* 48(4): 1377–1400.

Fries, J. F., B. Bruce and E. Chakravarty 2011. Compression of morbidity 1980–2011: a focused review of paradigms and progress. *Journal of Aging Research 2011*. Article ID 261702, 10 pages doi:10.4061/2011/261702.

Gan, L., G. Gong, M. Hurd and D. McFadden 2004. Subjective mortality risk and bequests. Technical report, National Bureau of Economic Research.

Geue, C., A. Briggs, J. Lewsey and P. Lorgelly 2014. Population ageing and healthcare expenditure projections: new evidence from a time to death approach. *The European Journal of Health Economics* 15(8), 885–896.

Hamermesh, D. S. 1985. Expectations, life expectancy, and economic behavior. *The Quarterly Journal of Economics* 100(2): 389–408.

Health and Retirement Study 2013. public use dataset. Produced and distributed by the University of Michigan with funding from the National Institute on Aging (grant number NIA U01AG009740). Ann Arbor, MI.

Human Mortality Database 2015. University of California, Berkeley (USA) and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org or www.humanmortality.de (data downloaded on February 27, 2015).

Hurd, M. D. and K. McGarry 1995. Evaluation of the subjective probabilities of survival in the health and retirement study. *Journal of Human Resources* 30: S268–S292.

Kapteyn, A., P.-C. Michaud, J. P. Smith and A. Van Soest 2006. Effects of attrition and non-response in the health and retirement study. Technical report, IZA Discussion paper.

Kutlu-Koc, V. and A. Kalwij 2013. Individuals survival expectations and actual mortality. *Netspar Discussion Papers* 2013–013.

Miller, T. 2001. Increasing longevity and medicare expenditures. *Demography* 38(2): 215–226.

Myrskylä, M., N. K. Mehta and V. W. Chang 2013. Early life exposure to the 1918 influenza pandemic and old-age mortality by cause of death. *American Journal of Public Health* 103(7): e83–e90.

Payne, J. W., N. Sagara, S. B. Shu, K. C. Appelt and E. J. Johnson 2013. Life expectancy as a constructed belief: Evidence of a live-to or die-by framing effect. *Journal of Risk and Uncertainty* 46(1): 27–50.

Perozek, M. 2008. Using subjective expectations to forecast longevity: Do survey respondents know something we dont know? *Demography* 45(1): 95–113.

Post, T. and K. Hanewald 2012. Longevity risk, subjective survival expectations, and individual saving behavior. *Journal of Economic Behavior & Organization* 86: 200–220.

R Core Team 2013. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

RAND 2013, September. RAND HRS Data, Version M. Produced by the RAND Center for the Study of Aging, with funding from the National Institute on Aging and the Social Security Administration.

Riffe, T., J. Schöley and F. Villavicencio 2017. A unified framework of demographic time. *Genus* 73(7).

Salm, M. 2010. Subjective mortality expectations and consumption and saving behaviours among the elderly. *Canadian Journal of Economics/Revue canadienne d'économique* 43(3): 1040–1057.

Sanderson, W. C. and S. Scherbov 2005. Average remaining lifetimes can increase as human populations age. *Nature* 435(7043): 811–813.

Sanderson, W. C. and S. Scherbov 2013. The characteristics approach to the measurement of population aging. *Population and Development Review* 39(4): 673–685.

Seshamani, M. and A. M. Gray 2004. A longitudinal study of the effects of age and time to death on hospital costs. *Journal of Health Economics* 23(2): 217–235.

Stearns, S. C. and E. C. Norton 2004. Time to include time to death? the future of health care expenditure predictions. *Health Economics* 13(4): 315–327.

Sullivan, D. 1971. A single index of mortality and morbidity. *HSMHA Health Reports* 86: 347–354.

United Nations, Department of Economic and Social Affairs, Population Division 2013. World population prospects: The 2012 revision, key findings and advance tables. Technical report, United Nations.

van Raalte, A. and T. Riffe 2016. Accounting for temporal variation in morbidity. Presented at the Annual Meeting of the Population Association of America.

van Solinge, H. and K. Henkens 2010. Living longer, working longer? the impact of subjective life expectancy on retirement intentions and behaviour. *The European Journal of Public Health* 20(1): 47–51.

Vaupel, J. W. 2009. Life lived and left: Carey's equality. *Demographic Research* 20(3): 7–10.

Villavicencio, F. and T. Riffe 2016. Symmetries between life lived and left in finite stationary populations. *Demographic Research* 35(14): 381–398.

Weir, D., J. Faul and K. Langa 2011. Proxy interviews and bias in the distribution of cognitive abilities due to non-response in longitudinal studies: a comparison of hrs and elsa. *Longitudinal and Life Course Studies* 2(2): 170.

Werblow, A., S. Felder and P. Zweifel 2007. Population ageing and health care expenditure: a school of red herrings? *Health Economics* 16(10): 1109–1126.

Wolf, D. A., V. A. Freedman, J. I. Ondrich, C. L. Seplaki and B. C. Spillman 2015. Disability trajectories at the end of life: A countdown model. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences* 70(5): 745–752.

Appendix: Variables and correlations

For the tables displayed in this appendix we use a shorthand to identify axis types. T indicates the correlation coefficient along the thanatological age axis. A indicates the chronological age axis. L indicates the lifespan axis (right-downward slanting isolines), which is the least common in these data. M indicates the mixed axis, or the upward-right slanting isolines, which is the most common type in these data. The code used to generate these and all other results, including the results for all five-year cohorts from 1905–1925 and different degrees of smoothing, is freely available from the repository. The repository also contains a csv of these summary results. https://github.com/timriffe/ThanoEmpirical.

Results are grouped by several major morbidity categories and presented in heatmap tables. In these tables, darker shades of gray indicate higher correlations (black = 1), and lighter shades of gray indicate low correlations (white = 0). Numbers inside the cells indicate the rounded Pearson's correlation coefficient × 100, and can be interpreted as percents.

Finally, it bears noting that these values say nothing about prevalence levels. They are only intended to serve as rough gauges of the direction of variation in characteristics.

List of Appendix tables

Table A.1:
Activities of Daily Living (ADL)

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
ADL3	ADL 3 point	25	80	80	96	9	67	84	89
ADL5	ADL 5 point	23	79	81	97	5	65	87	89
WALK	Difficulty walking across room	16	73	83	93	6	53	86	80
DRESS	Difficulty dressing	18	75	82	94	8	66	85	89
BATH	Difficulty bathing or showering	17	73	81	94	7	59	83	82
EAT	Difficulty eating	19	70	72	91	15	65	79	85
BED	Difficulty getting in/out bed	14	71	82	93	8	59	80	80
TOILET	Difficulty using toilet	31	81	73	94	0	51	81	78

Table A.2:
Instrumental Activities of Daily Living (IADL)

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
IADL3	IADL 3 point	28	82	78	97	6	66	88	91
IADL5	IADL 5 point	14	74	87	96	7	68	89	92
WORK	Health limits work	25	36	98	73	6	53	93	84
MAP	Difficulty using maps	24	77	78	94	13	67	80	88
TEL	Difficulty using telephone	33	83	68	96	20	75	78	95
MONEY	Difficulty managing money	21	76	81	95	1	56	90	84
MEDS	Difficulty taking medications	24	75	77	95	3	45	94	73
SHOP	Difficulty grocery shopping	2	65	91	91	8	54	91	84
MEALS	Difficulty prep. hot meals	20	76	82	95	6	60	88	85

Table A.3:
Health behaviors

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
ALCEV	Alcohol, ever-drinker	40	79	62	88	8	41	78	68
ALCDAYS	Drinking days / week	10	48	77	72	18	40	77	67
ALCDRINKS	Nr drinks per drinking day	28	84	75	96	18	49	89	80
SMOKEEV	Ever-smoker	98	81	27	48	87	68	30	37
SMOKECUR	Current-smoker	83	93	16	77	91	86	10	54

Table A.4:
Functional limitations

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
BMI	Body mass index	34	79	72	93	4	54	91	83
BACK	Back problems	56	91	43	82	79	92	17	74
MOB	Mobility difficulty index	16	76	86	97	1	64	92	92
LGMUS	Large muscle difficulty index	32	85	77	99	11	72	88	95
GROSSMOT	Gross motor difficulty index	10	71	88	94	5	65	87	89
FINEMOT	Fine motor difficulty index	22	78	81	96	14	70	81	90

Table A.5:
Chronic conditions

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
CC	Number of chronic conditions	34	82	77	98	7	53	95	84
BP	High blood pressure, ever	14	67	84	89	37	84	75	98
DIAB	Diabetes, ever	72	22	80	21	69	28	65	10
CANCER	Cancer, ever	29	31	96	68	17	41	93	75
LUNG	Lung disease	62	7	88	36	90	50	65	7
HEART	Heart problems, ever	26	78	82	97	23	37	96	73
STROKE	Stroke, ever	46	90	69	99	9	51	95	82
PSYCH	Psychological problems, ever	33	77	69	88	24	37	96	72
ARTH	Arthritis, ever	75	92	28	82	69	91	33	84

Table A.6:
Cognitive function

Short	Description	Females L	Females A	Females T	Females M	Males L	Males A	Males T	Males M
SRM	Self-rated memory	51	92	65	99	60	70	16	60
PASTMEM	Memory compared to past	61	87	41	85	71	94	36	87
SS	Serial 7s	1	64	92	91	7	48	60	65
C20B	Backwards counting	35	81	66	90	30	79	72	93
NAMEMO	Naming month	33	80	67	90	2	49	72	70
NAMEDMO	Naming day of month	24	78	78	94	21	75	78	92
NAMEYR	Naming year	44	88	64	95	19	74	80	93
NAMEDWK	Naming day of week	16	72	80	91	20	70	73	86
NAMESCI	Naming scissors	50	87	53	88	12	42	78	69
NAMECAC	Naming cactus	39	86	68	95	56	86	45	84
NAMEPRES	Naming president	17	74	82	93	59	3	81	37
NAMEVP	Naming vice president	1	52	74	74	4	58	79	81
VOCAB	Vocabulary score	40	10	67	42	51	13	85	53
TM	Mental status summary	19	76	83	96	10	66	81	87
DWR	Delayed word recall	4	59	87	85	19	71	82	92
TWR	Total word recall	19	71	82	92	27	76	77	93
IWR	Delayed word recall	33	80	76	96	35	80	71	93

Table A.7:
Psychological well-being

Short	Description	Females L	Females A	Females T	Females M	Males L	Males A	Males T	Males M
CESD	Depression score	44	19	91	58	22	43	95	78
SRH	Self-reported health	42	14	90	53	29	33	98	70
DEPR	Felt depressed	55	19	58	13	58	4	86	38
SLEEP	Sleep restless	45	4	65	28	55	3	91	45
HAPPY	Was happy	33	15	76	47	15	60	72	78
LONE	Felt lonely	32	64	50	71	7	64	90	90
SAD	Felt sad	69	39	47	7	22	35	91	69
GOING	Could not get going	70	15	87	30	22	36	92	70
ENJOY	Enjoyed life	13	40	85	70	42	85	67	95

Table A.8:
Health care use (24 months)

Short	Description	Females				Males			
		L	A	T	M	L	A	T	M
HOSP	Overnight hospital	26	73	75	90	11	60	77	81
HOSPSTAYS	Number hospital stays	5	57	80	83	4	50	86	78
HOSPNIGHTS	Number nights in hospitals	10	40	77	70	61	6	87	36
NH	Overnight stay in nursing home	25	75	67	94	13	64	78	82
NHSTAYS	Nursing home stays	26	76	67	94	10	57	77	78
NHNIGHTS	Number nights in nursing homes	18	70	70	89	13	61	80	80
NHNOW	Nursing home at interview	14	72	71	93	8	46	80	73
DOC	Visited doctor	63	89	40	85	52	85	52	88
DOCVISITS	Number of doctor visits	54	91	58	95	33	70	56	79
HHC	Home health care	18	71	84	94	2	52	90	84
MEDS	Prescription drugs regularly	22	40	90	73	23	41	92	75
SURG	Outpatient surgery	32	11	31	7	30	17	18	3
DENT	Visited dentist	84	33	75	14	27	11	55	35
SHF	Visited special healthcare facility	35	87	75	99	12	71	87	94

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A cross-national comparison of 12 biomarkers finds no universal biomarkers of aging among individuals aged 60 and older

David H. Rehkopf, Luis Rosero-Bixby and William H. Dow*

Abstract

There is uncertainty about whether biological and anthropometric measures that are clinical risk factors for disease are universally associated with chronological age, or whether these correlations vary depending on the social and economic context. The answer to this question has implications for the malleability of biological aging. To examine this issue, we use population-based data on individuals aged 60 and older from the Costa Rican Study on Longevity and Healthy Aging, and temporally consistent data from the United States National Health and Nutrition Examination Survey and the United States Health and Retirement Study. Our analysis focuses on 12 biomarkers that have been shown in the literature to have an association with age, and that occur prior to the clinical manifestation of disease. We find that there are few consistent patterns of association with age when these biomarkers are stratified by gender, country, and level of education. This result suggests that these measures of biological aging are highly context-dependent, and that none of the 12 biomarkers we examined are universal biomarkers of aging. Future research that investigates composite measures of biological age should test newly proposed measures across gender, social class, and country.

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1 Introduction

While there are many definitions of biomarkers of aging, the following is widely used: “A biomarker of aging is a biological parameter of an organism that either alone or in some multivariate composite will, in the absence of disease, better predict functional capability at some late age than will chronological age” (Baker and Sprott 1988). This definition makes explicit a fundamental question in aging research: namely, are aging and disease separate entities, or is the former just a consequence of the latter? A primary motivation for studying biomarkers of aging is to determine whether we can characterize the aging process separately from disease. To support the identification of potential biomarkers of aging, Baker and Sprott described six characteristics of a biomarker of aging: (1) the rate of change of a biomarker must reflect some measureable parameter that can be predicted at a later chronological age; (2) the biomarker should reflect some basic biological process of aging, and not a predisposition to a disease state or some inborn error in metabolism; (3) the biomarker should have a high degree of reproducibility in cross-species comparisons of functional or physiological age and chronological age, particularly within the same classes, and certainly within the same families of species; (4) the biomarker should change independently with the passage of time, and reflect physiological (functional) age; (5) the assessment of the biomarker should be nonlethal in animal systems, and should cause minimal trauma in humans; and (6) the biomarker should be reproducible and measureable during a relatively short time interval. Meanwhile, the American Federation for Aging Research (AFAR) proposed four criteria for identifying a biomarker of aging: (1) the biomarker must predict a person’s physiological, cognitive, and physical functioning in an age-related way; (2) the biomarker must monitor the basic process underlying aging, and not the effects of disease; (3) the biomarker must be testable and not harmful to subjects; and (4) the biomarker should work in laboratory animals as well as in humans (Johnson 2006).

While these criteria reflect a wide range of characteristics, in our analysis we will focus on the assessment of three of the most fundamental criteria: (1) the passage of time, (2) the underlying physiological process, and (3) reproducibility. The first and primary focus of our analysis is to assess whether the biomarker has some fundamental relationship with the passage of time in an individual’s life; that is, with the individual’s chronological age. In the definition of biomarkers of aging, this point is explicated in the requirement that the marker reflect the rate of aging. For example, the Baker and Sprott criteria stated that “biomarkers should change independently with the passage of time;” while the AFAR criteria stipulate that a biomarker should function in an “age-related way.” This point was made even more explicitly in the 1987 National Institute of Aging primate study, which stated that the first step in defining a biomarker of aging is establishing that it has a “significant cross-sectional correlation with age” (Ingram, Nakamura, Smucny, Roth and Lane 2001). While chronological age is only one of many criteria, it is fundamental to the definition of a biomarker of aging. Our primary investigations use conventional age, measured as the time elapsed since birth, as the metric. Most of the biomarker definitions and research on biomarkers have relied on this definition of age. However, a secondary focus of our analysis also uses the metric of thanatalogical age, or the time before death. As we are examining all individuals in the data in the years prior to their death, we use this metric to explore the question of whether biomarkers meet another criterion put forth by Butler: namely, that a biomarker of aging "should predict remaining longevity at an age when 90% of the population is still alive" (Butler et al. 2004).

The second criterion we consider in our analysis of the biomarkers of aging is the underlying physiological process. This criterion has been broadly described in the criteria outlined by Baker and Sprott as "some basic biological process of aging." We thus cast a narrower net than some other studies which examined any physiological parameter that had been measured, even if it had no clear connection to biological aging or pathobiology. We include only biomarkers that have a known function and that are related to illness. These criteria are also consistent with other expectations of biomarkers of aging, as defined by Arking: namely, that a biomarker of aging must "be crucial to the maintenance of health" and "be monitoring some basic, important process" (Arking 2006). Moreover, this approach is in line with the recent definition of a biomarker of aging issued by the American Federation for Aging Research, in which one of the criteria is that a biomarker of aging must "monitor the basic process underlying the aging process, not the effects of disease." The use of biologically well-characterized risk factors for disease gives us a higher degree of confidence that these are indeed risk factors of disease, and not the effects of disease – a certainty we lack when we look at many of the hypothesized biomarkers of aging that, for example, capture aspects of immune function. This is not to argue that these other factors are not potentially important as biomarkers of aging; rather, we are noting that we can be less certain that they are not consequences of the disease process. Based on these criteria, we included the following 12 potential biomarkers of aging in our analyses: systolic blood pressure, diastolic blood pressure, HbA1c, fasting glucose, C-reactive protein, HDL cholesterol, triglycerides, total cholesterol, urinary creatinine, body mass index (BMI), waist circumference, and leukocyte telomere length. All of these biomarkers have been investigated in prior studies of biomarkers of aging (Crimmins, Vasunilashorn, Kim and Alley 2008; Mather, Jorm, Parslow and Christensen 2011). Six of these factors (systolic blood pressure, diastolic blood pressure, total cholesterol, HDL cholesterol, HbA1c, and waist circumference) are components of the calculation of allostatic load, which has been proposed as a biomarker index of aging (Johnson 2006; Karlamangla, Singer, McEwen, Rowe and Seeman 2002; Seeman, McEwen, Rowe and Singer 2001), and has been shown to be associated with all-cause mortality (Karlamangla, Singer and Seeman 2006). A large number of scholars have also speculated about the use of leukocyte telomere length as a biomarker of aging (Boonekamp, Simons, Hemerik and Verhulst 2013; Der et al. 2012; Mather et al. 2011; Sanders and Newman 2013).

Third, we use a population-based approach to assess reproducibility; i.e., to examine whether each biomarker has a consistent relationship with age. In both early and more recent definitions of a biomarker of aging, the criteria of "high reproducibility in cross-species comparisons" (Baker and Sprott 1988) and "something that works in humans and in laboratory animals, such as mice" are mentioned. Rather than examine whether each biomarker is associated across species, we examine whether each biomarker is associated with age in a similar manner across humans who are exposed to different environments, both within a country and between countries. This approach complements much of the previous lab-based research on biomarkers of aging (Zahn et al. 2007) and non-human mammal-based approaches (Nadon 2006). In our examination, we explicitly apply this approach to humans, acknowledging that the wide range of environments in which humans live could affect the utility of biomarkers for measuring aging. Our approach is based on the theoretical concept of embodiment; i.e., that the environment in which humans live has profoundly important effects on their physiology (Krieger 2005). An indicator could still be considered a biomarker of aging even if the rate at which it deteriorates with age varies across environments; as long as the indicator worsens to some degree with age, we can consider it a "weakly universal" biomarker of aging. An indicator with a slope that does not differ across environments could be termed a "strongly universal" biomarker of aging. However, if in some environments the age slope of an indicator reverses to improve with age, we can reject that particular biomarker as a candidate for a universal biomarker of aging.

The primary purpose of this article is thus to describe how 12 potential biomarkers of aging are correlated with age, or with the number of years since birth. A secondary goal is to examine how the 12 potential biomarkers are correlated with thanatological age, or with the number of years until death. The first minimal criterion we will use to test whether each of these factors qualifies as a biomarker of aging is whether the physiological levels of the biomarker worsen with a greater number of years since birth. The second criterion we will use to test whether each of these biomarkers acts as a biomarker of aging is whether the correlation is consistent across sexes, countries, and levels of education. In proposing these criteria, which are based directly on definitions of biomarkers of aging, we wish to emphasize that they are necessary but not sufficient criteria for identifying biomarkers of aging. Our descriptive, population-based approach is intended to contribute to efforts to establish the validity and reliability of potential biomarkers of aging.

We also wish to note that work has been done to combine biomarkers into composite measures of biological aging. A study on a younger birth cohort in New Zealand used a combination of 18 biomarkers to characterize biological aging, including a majority of the clinical measures we examine here (Belsky et al. 2015). While this study showed that most of these biomarkers were associated with age, this research is somewhat limited because it examined the biomarkers at three ages only (26, 32, and 38), and because it is unclear whether findings from this population can be generalized to other contexts. Another study using data from the United

States from a wider age range has shown that many of the biological risk factors we examine are associated with age (Levine 2013). But as with the research for New Zealand, it is not clear whether these relationships hold across different contexts and levels of education, and whether the associations with age are non-linear. In our study, we extend these analyses to examine whether the individual measures have consistent relationships with age across country, gender, and social class.

2 Data and Methods

2.1 Study Samples

2.1.1 Costa Rica

The data on Costa Rica were drawn from the Costa Rican Study on Longevity and Healthy Aging (CRELES), a longitudinal, nationally representative, probabilistic sample of close to 3,000 adults aged 60 and older, with an over-sampling of older ages (Rosero Bixby, Fernandez and Dow 2010). The current study used data from the first wave of data collection, which took place mainly in 2005. The sample size varied depending on the biomarker, as described in the Table 1 note. The dates of each participant's birth and death were taken from the national registry databases using the participant's "*cédula*" number (the Costa Rican identification card number). A computerized death registry follow-up to establish the deaths of participants was accessed up to March 2014, at which point 60% of observations were survivors with between 5.6 and 9.4 years of follow-up. Because foreigners (3% of the sample) cannot be accurately followed in the death registry, they were excluded from the thanatological age analysis. For all analyses of the CRELES sample, we used data from two observations where available, and accounted for the clustered nature of this sample in calculating our standard errors for the regression models. The number of deaths used for the calculation of thanatological age was 1,214. Because we were interested in using the exact rather than the predicted thanatological age, we used only individuals who were deceased in the thanatological age calculations. No upper age limit was placed on the Costa Rica sample.

2.1.2 United States

To maximize our sample sizes and range of biomarkers, the data we use for the United States have been drawn from two separate surveys. The first U.S. dataset is from the Health and Retirement Study (HRS). The HRS began in 1992 with a nationally representative sample of non-institutionalized US residents born in 1931–1941, and their spouses. The individuals in the original panel were surveyed every two years across broad categories of survey content, with special focuses on income, work, assets, and self-reported physical health and functioning. To maintain the age 50+ representative nature of the sample, supplemental sampling is used to recruit new samples. The Survey Research Center at the University of Michigan provided detailed documentation on the HRS sampling design and the selection and validation of health measures (Juster and Suzman 1995). We implemented our analytic models using the HRS Rand Files Version L (RAND 2011). Our HRS sample was taken from the samples used in 2006 and 2008, the years when the biomarker data were collected. In order to match the age distribution of the CRELES sample, we excluded from our HRS analytic sample individuals aged 59 and younger. The final analytic sample consisted of 5,870 men and 9,008 women. The number of deaths used for the calculation of thanatological age was 1,650. These deaths were drawn from data linked to the U.S. National Death Index (Rogot et al. 1983). There is no upper age limit on the HRS population.

Data were also obtained from a separate survey with many additional biomarkers, the U.S. National Health and Nutrition Examination Survey (NHANES) 1999–2004. This survey covered non-institutionalized adults aged 60 and older ($n = 2411$ men, $n = 3196$ women). This cross-sectional dataset is representative of the non-institutionalized population of the United States. Because individuals aged 85 and older are top-coded to an age 85+ category, we excluded individuals aged 85 and older from this U.S. sample. Except for the measures shown as not collected in the HRS, which are displayed in descriptive Table 1, all of the analyses of the U.S. context included individuals from both the HRS and the NHANES. The number of deaths used for the calculation of thanatological age was 329. These deaths were drawn from data linked to the U.S. National Death Index (Rogot et al. 1983)

2.2 Measures

Systolic and diastolic blood pressure were measured using the average readings over multiple measures per individual. Blood glucose was measured after fasting. Creatinine was measured from urine. BMI was calculated from weight and height measured at the time of each survey. Leukocyte telomere length was measured using the PCR-based method in all three samples (Cawthon 2002; Needham et al. 2013; Rehkopf et al. 2014). Further details on the measurement of each biomarker in each survey are described elsewhere (NCHS 1999; Rosero-Bixby and Dow 2012; Weinstein, Vaupel, Wachter and Weir 2008). Urinary creatinine, triglycerides, and glucose were not measured among the HRS participants. The following exclusions were made for biologically implausible values: HbA1c >= 12%, fasting glucose >= 400 mg/dl, diastolic blood pressure <= 20 mm Hg, trigylcerides >= 700 mg/dl, total cholesterol >= 400 mg/dl, urinary creatinine >= 400 mg/dl, leukocyte telomere length t:s ratio > 6, BMI > 70 kg/m^2. We also excluded individuals with C-reactive protein levels >= 5 mg/dl because the intent of using this biomarker for aging is to capture systemic inflammation, rather than acute inflammatory response to infection (Ridker 2003; Steel and Whitehead 1994).

In order to compare individuals across social environments within each country by education, while taking into account the differences in the implications of education across countries, education was divided into three major categories in each country. For Costa Rica, educational attainment was categorized as follows: less than three years of education, between three and six years of education (elementary school comprises six grades), and at least one year of high school. For the United States, we used the following educational categories: less than high school, high school, and more than high school.

2.3 Statistical analysis

In order to account for the potential non-linear relationships between age and biomarkers, we fitted generalized additive models that allow for a multiple slope spline, but penalize for overfit with internal cross validation. Thus, a linear model is used if it offers the best fit for the data penalized by degrees of freedom (Wood 2006). Figures 1–6 show a straight line if a linear model was the best fit for the data, or a curved line if a non-linear model was the best fit for the data. While the extent of the differences in the associations with age can be observed in these figures, we also fitted models with interaction terms that allow us to test statistically whether there are different associations between the biomarker and age by gender, place, and education.

Finally, we also fitted models that include all covariates in a generalized additive model to examine the overall variance in age that can be explained by all 12 biomarkers within each country context. Because there is no single slope that can be used to quantify the magnitude of the impact of each of the parameters in these models, we present the estimated degrees of freedom, the overall F-statistics, and the p-values that can be used to assess the relative strength of the association of the covariates within each model. A direct comparison of the test statistics across the models is not appropriate because the different sample sizes in each country will affect the sizes of the F-statistics and the p-values in the various models for associations of a similar magnitude. The models are run on the samples that had all covariates measured.

In order to avoid the bias caused by complete case analysis, we imputed missing observations for all variables using a nonparametric missing value imputation with Random Forest, implemented using the R package missForest (Stekhoven and Bühlmann 2012). This approach has several advantages relative to multiple imputation methods for missing data, including that it can be used with non-linear models. This method of imputing missing data has been shown to compare favorably with other missing data imputation approaches. In a validation test, the missForest algorithm was found to have the smallest prediction difference between the imputed and the non-missing datasets (Waljee et al. 2013).

Sample weights are used for all analyses. The weights range from zero to 4.61, with a mean of 1.0 within each sample, and an overall mean of 0.98.

Table 1:
Quantiles of the distribution (15th, 50th, and 85th) of biomarkers by study population

	CRELES			HRS			NHANES		
	15th	50th	85th	15th	50th	85th	15th	50th	85th
Age	62	69	79	65	72	83	62	69	78
Systolic	120	142	168	113	131	154	116	135	160
Diastolic	71	82	95	66	77	89	58	70	82
HbA1c	5.1	5.5	6.4	5.2	5.7	6.5	5.2	5.5	6.3
Glucose	81	94	128	NA			85	95	116
CRP	0.2	0.3	0.8	0.1	0.2	0.7	0.1	0.3	0.8
HDL cholesterol	31	42	56	37	52	70	37	51	70
Triglycerides	87	144	244	NA			85	138	233
Total cholesterol	168	211	263	155	193	244	170	209	251
Creatinine	30	56	115	NA			37	94	170
BMI	22	26	32	22	26	33	23	27	33
Waist	82	93	106	81	99	116	85	100	115
Telomere length	0.8	1.0	1.2	1.0	1.2	1.6	0.7	0.9	1.1

Note: NA indicates that this biomarker was not collected in the HRS sample. Systolic and diastolic blood pressure are mm Hg, HbA1c is percent, glucose is mg/dl, CRP is mg/dl, HDL cholesterol is mg/dl, triglycerides is mg/dl, total cholesterol is mg/dl, creatinine is mg/dl, BMI is kg/m^2, waist is cm, telomere length is T/S ratio of leukocyte telomere length. The total sample sizes are as follows: 2,880 for CRELES, 13,634 for HRS, and 4,975 for NHANES. The sample sizes for each biomarker are as follows for CRELES, HRS, and NHANES, respectively: systolic (n = 2309, n = 12914, n = 4290), diastolic (n = 2309, n = 12893, n = 4199), HbA1c (n = 2295, n = 13274, n = 4277), glucose (n = 2318, NA, n = 4194), CRP (n = 1264, n = 6537, n = 2569), HDL cholesterol (n = 2313, n = 10904, n = 2734), triglycerides (n = 2315, NA, n = 2091), total cholesterol (n = 2316, n = 12662, n = 4210), creatinine (n = 1131, NA, n = 4336), BMI (n = 2304, n = 13633, n = 4106), Waist (n = 2178, n = 6999, n = 4039), telomere length (n = 1248, n = 5946, n = 1196).

3 Results

Table 1 presents the 15th, 50th, and 85th percentiles of the distribution of age, and for each of the 12 biomarkers we examined stratified by each of the three datasets; namely, the CRELES sample from Costa Rica, and the NHANES and the HRS samples from the United States. The table note describes the overall sample size for each dataset and the available sample for each biomarker. The distribution of age differs slightly across datasets due to the nature of the age sampling in each of the surveys. In particular, we note that because the public-use NHANES data do not identify by age individuals aged 85 and older, these individuals were not included in our analysis. Because all of our analyses are examined relative to age, small differences in the age distribution do not affect our findings. It is also important to note that only around 15% of the samples consist of individuals aged 80 and older, which limits the potential for bias due to mortality selection in our samples.

While the overall biomarker levels differ slightly across the samples, they are generally in the same range. Levels of systolic and diastolic blood pressure were a bit higher in the CRELES sample than in the HRS and NHANES samples. Urinary creatinine was higher in the NHANES sample, while waist circumference was lower in the CRELES sample.

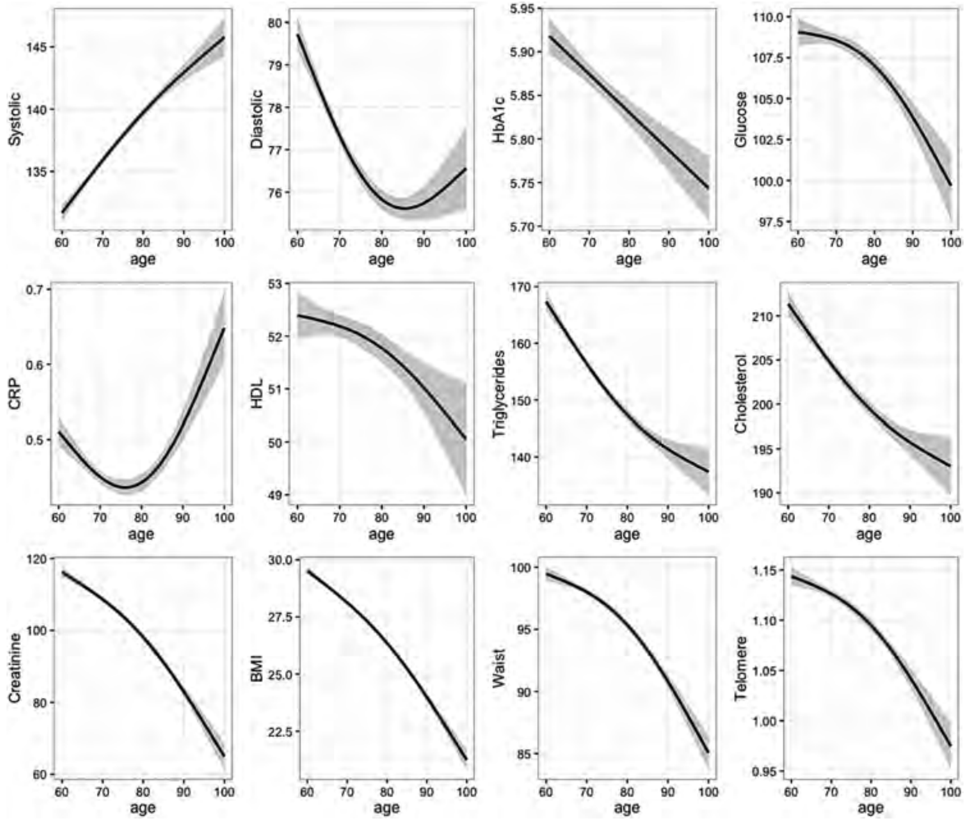
Figure 1 shows the relationship between age and each of the 12 biomarkers in the pooled database that includes all three samples. The plots are based on associations using a generalized additive model that allows for a non-linear dependence between age and the biomarkers. The light gray areas show 95% confidence intervals of the model-based associations. We observe a strong relationship with age across all 12 of these measures, consistent with our *a priori* hypothesis and with the findings of other literature. For biomarkers that are associated with worse health, the direction of the association is not in all cases in the expected direction of higher biomarker levels at older ages. For eight of the 12 biomarkers – diastolic blood pressure, HbA1c, glucose, triglycerides, total cholesterol, BMI, creatinine, and waist circumference – older age is associated with better values. Thus, of the measures that were chosen as biomarkers with important implications for health, the levels worsen with increasing age for only four. Of these four biomarkers that exhibit the expected trajectory with increasing age, two of these relationships generally worsen linearly with age (systolic blood pressure and HDL cholesterol), and two have a non-linear threshold relationship whereby the association with age is stronger after around age 75 (CRP and telomere length).

Figure 2 shows the same associations in the pooled samples, but now the associations are age-stratified by gender (the black line shows the associations among women, while the dark gray line shows the associations among men). When we look at the four biomarkers that have been shown to worsen with age in the overall population, we see that these relationships differ between men and women. While the relationship for systolic blood pressure holds in both genders, it is much stronger among women. The HDL cholesterol biomarker improves with age up to age 80 among women. For CRP, the relationship with age is strong among men only. For telomere length, the shortening of the telomere length with age is found among men only.

When we look at the factors that were not found to worsen with increasing age in the general population, we see that different associations emerge when the results are stratified by gender. For diastolic blood pressure, we find that levels increase with age among women aged 80 and older; for HbA1c, we see that levels rise with age among men aged 75 and older; and for glucose, we find that levels increase among women aged 75 and older.

Figure 3 presents the same analyses as those displayed in Figure 2, but now additionally stratified by country. The black lines are for women, the dark gray lines are for men, the solid lines are for Costa Rica, and the dashed lines are for the United States. About half of the associations between age and biomarkers that we examine are consistent across genders and places. The relationship is most consistent for BMI, with levels of BMI declining with age across genders and countries. The relationships between triglycerides, total cholesterol, and waist circumference are also generally similar across these four groups. For both systolic and diastolic

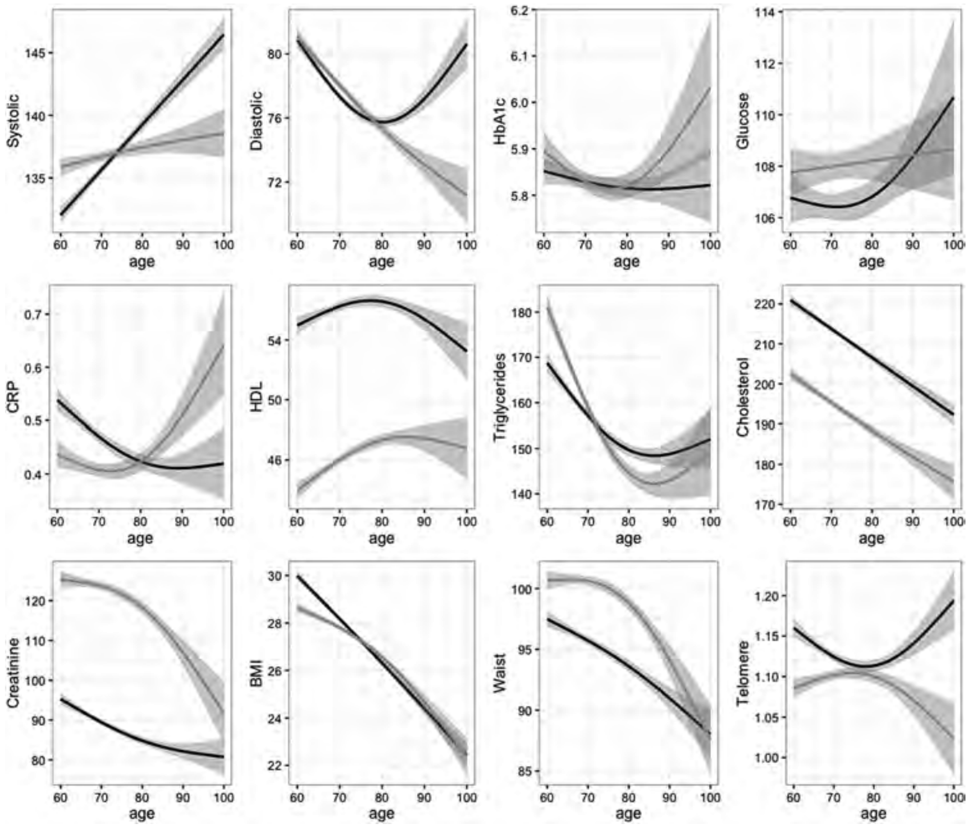
Figure 1:
The association between age and biomarkers



blood pressure, the patterns are generally similar up until around the age of 80. Thus, systolic blood pressure up to the age of 80 is the only biomarker of the 12 we examine that worsens with age across genders and country environments. The most clearly divergent patterns are observed for CRP among women, with the levels increasing with age in Costa Rica and decreasing with age in the U.S.; and for HDL cholesterol, with the levels decreasing with age in the United States and increasing with age in Costa Rica.

Figure 4 presents associations between biomarkers and age stratified by gender and level of education. The black lines are for women, the dark gray lines are for men, the solid lines are for individuals with lower levels of education, and the dashed lines are for individuals with higher levels of education. As in the previous models stratified by gender and education, we find that around half of the biomarkers had similar relationships with age across the four strata. Again, the relationships were

Figure 2:
The association between age and biomarkers by gender

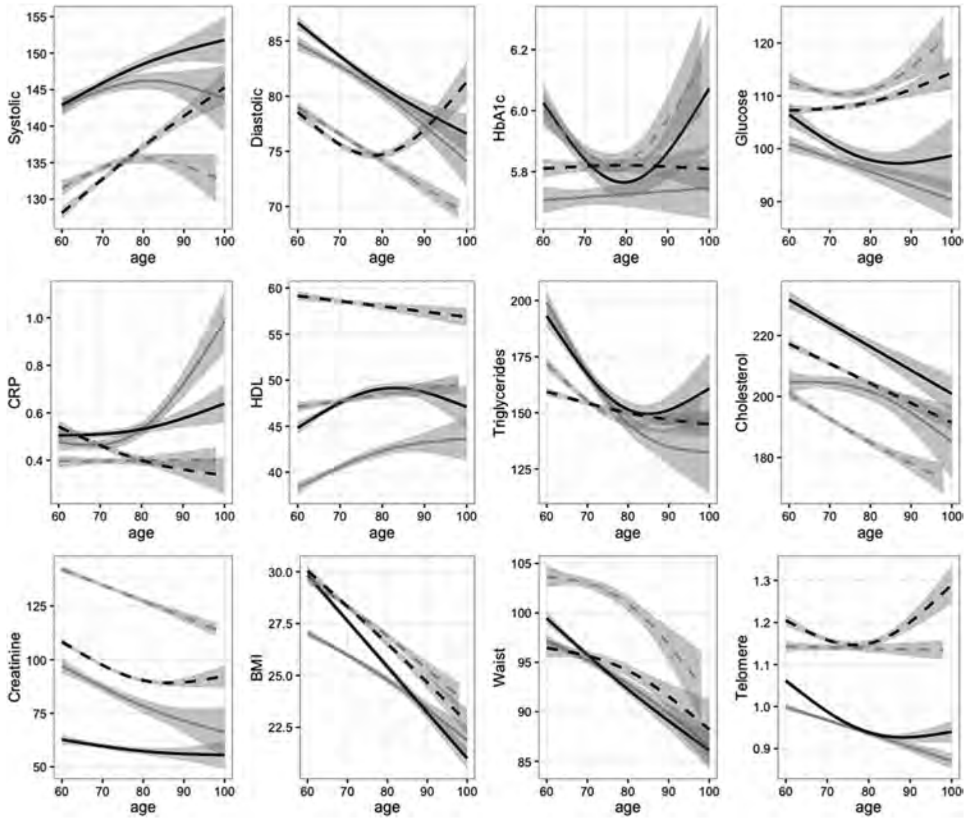


Note: black line is for women, dark gray line is for men.

most similar for BMI, waist, triglycerides, and cholesterol; but in all of these cases the levels declined with age. Moreover, as in the models stratified by country, we see that systolic blood pressure increased with age up to around age 85 – the only portion of the age distribution for any variable that showed worse biomarker levels at higher ages.

The prior analyses were all focused on years of age, which is the standard metric for examining biomarkers of aging. However, other scholars have suggested that thanatological age may be a more relevant metric, because it specifically acknowledges that there is a great deal of life expectancy heterogeneity (Riffe 2015). As years of age from birth compares people with different cumulative insults at a given age, these universal slope comparisons can be difficult to interpret. Thanatological age, which measures years before death, represents a different

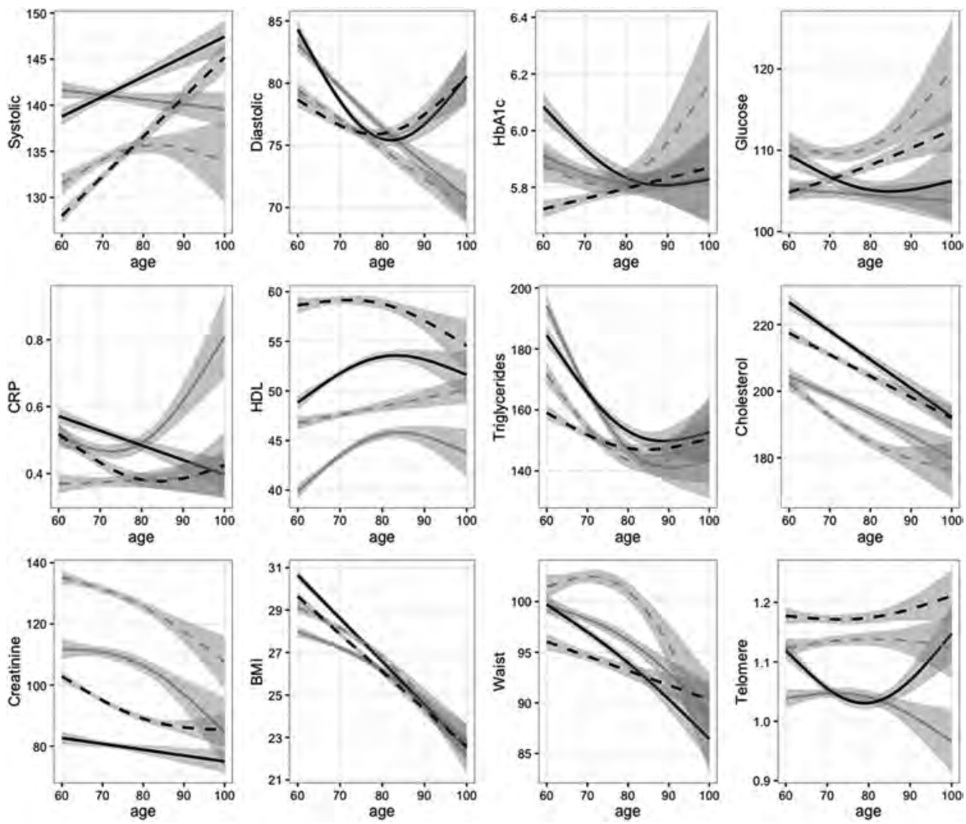
Figure 3:
The association between age and biomarkers by gender and country



Note: black lines are for women, dark gray lines are for men, solid lines are for Costa Rica, dashed lines are for the United States.

metric for comparing biomarker patterns with aging, while alternately standardizing average disease states. For these analyses, we operationalize thanatological age as years before actual death among our participants who died during the follow-up (rather than life expectancy, which can also be done). The results for the pooled samples are shown in Figure 5. When we compare these findings with the results presented in Figure 1, we see both similarities and differences. For eight of the 12 factors we examined, the biomarker associations with age from birth were similar to those with thanatological age (glucose, CRP, HDL cholesterol, triglycerides, cholesterol, creatinine, BMI, and waist circumference). For one other factor, HbA1c, there was a negative association with age, but no association with thanatological age. For three other biomarkers – systolic blood pressure, diastolic blood pressure, and telomere length – the associations between age and thanatological age were in

Figure 4:
The association between age and biomarkers by gender and education

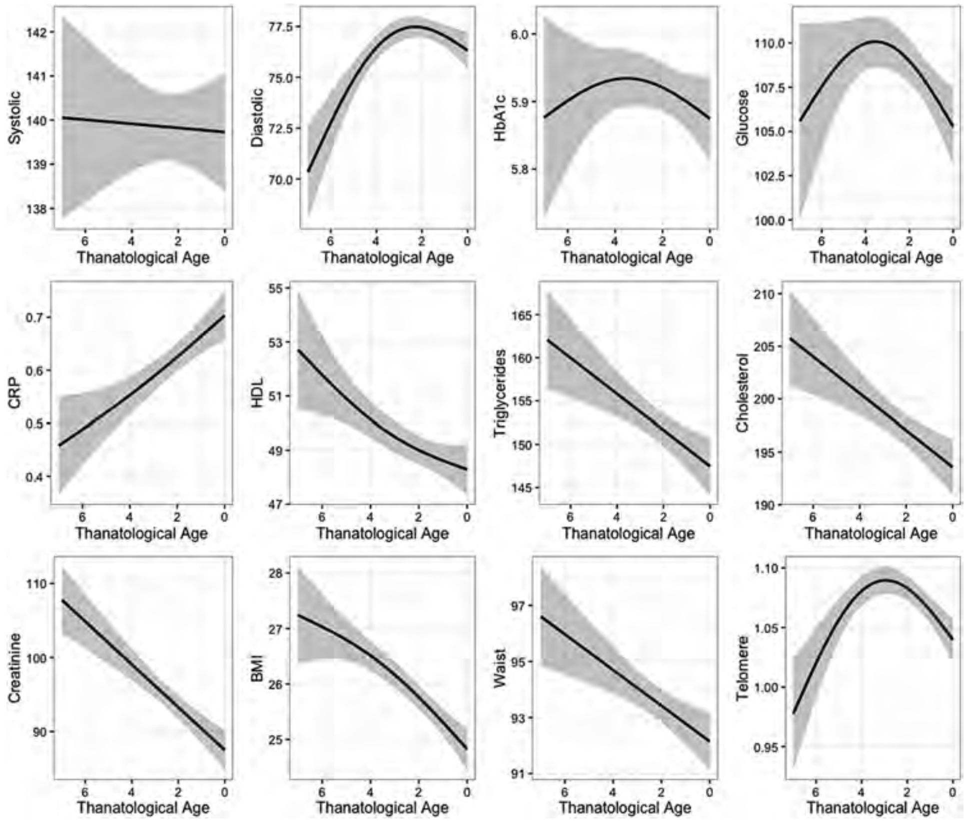


Note: black lines are for women, dark gray lines are for men, solid lines are for lower education, dashed lines are for higher education.

the opposite direction. In the years close to death, levels of systolic blood pressure were lower, but levels of diastolic blood pressure were higher and telomeres were longer. When we look at all 12 biomarkers in the aggregated overall population, we see that diastolic blood pressure, CRP, and HDL cholesterol were the only biomarkers that worsened as the number of years until death declined.

A feature worth noting in Figure 5 is that in half of the markers, the relationship with thanatological age is curvilinear: at about two to four years before death the slope of the association changes for diastolic blood pressure, HbA1c, fasting glucose, BMI, and telomere length. These changes in slope assume two general forms. In one form there is an association with age up until two to four years before death, but this association disappears in the two to four years immediately before death (diastolic blood pressure, HbA1c, and telomere length). In contrast, for

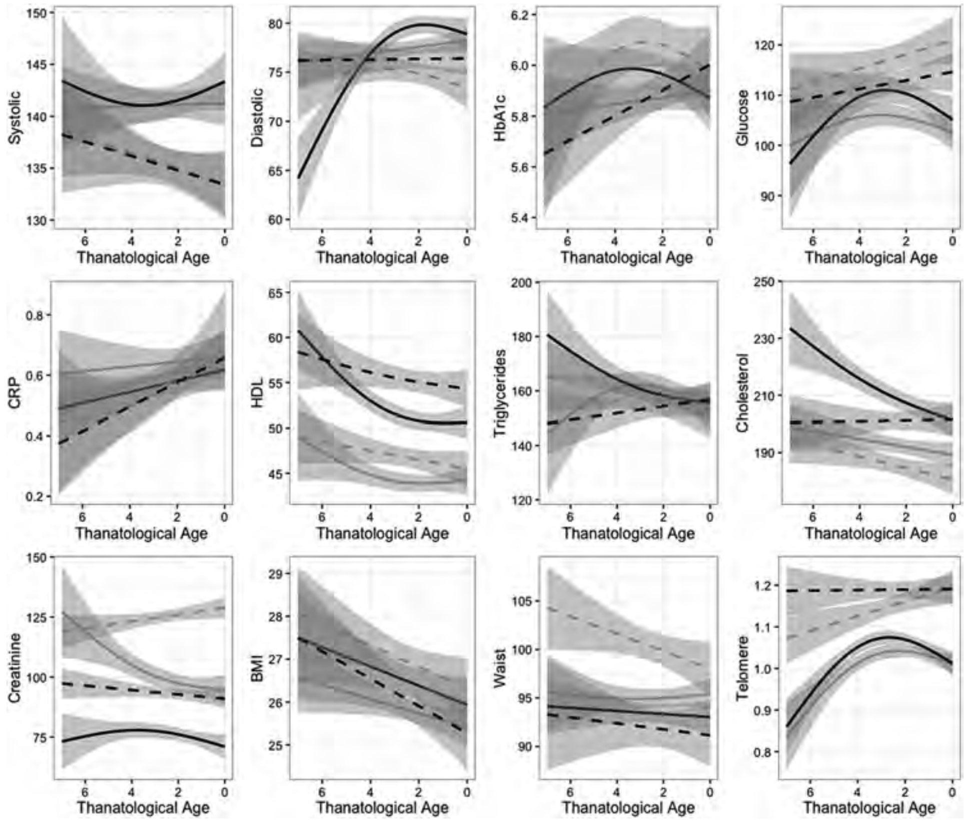
Figure 5:
The association between thanatological age and biomarkers



fasting glucose and BMI, a relationship with age is observed only in the two to four years immediately prior to death, during which levels of both of these biomarkers decrease.

In a final analysis of the relevance of thanatological age, we examine the relationship stratified by gender and level of education. We hypothesized that these thanatological relationships might be more closely aligned with biological aging than relationships with age from birth, because life expectancy differs considerably by both gender and level of education. In contrast to our hypothesis, we find that the heterogeneity of associations between population strata and thanatological age are similar, but not identical, to those with age since birth. For example, while we observe consistent associations for HDL cholesterol, CRP, BMI, and waist circumference with chronological age; we find more deleterious levels closer to death for HDL cholesterol and CRP.

Figure 6:
The association between thanatological age and biomarkers by gender and education



Note: black lines are for women, dark gray lines are for men, solid lines are for lower education, dashed lines are for higher education.

When we examine the curvilinear associations observed in the combined population, we see that most of these non-linear associations are found only within particular subgroups of the population, or not at all. For diastolic blood pressure, the threshold association is found primarily among women with lower levels of education. For HbA1c, fasting glucose, and telomere length, the threshold relationship is observed among those with lower levels of education; whereas an association with age is found only up until two to four years before death. When stratified by these four groups, the lower levels of BMI closer to death are fairly linear across thanatological ages. For urinary creatinine, the curvilinear relationship is found among men. For diastolic blood pressure, the strong relationship with age up until two to four years prior to death is observed among individuals with lower levels of education.

Table 2:
P-values for the interaction terms between age and gender, age and place, and age and education

	Gender p-value	Place p-value	Education p-value
Diastolic	<0.001	<0.001	<0.001
Systolic	<0.001	<0.001	<0.001
Total cholesterol	0.277	0.911	<0.001
BMI	0.158	<0.001	<0.001
Telomere length	<0.001	<0.001	0.002
HbA1c	<0.001	<0.001	<0.001
Creatinine	<0.001	<0.001	<0.001
CRP	0.587	0.661	0.804
Triglycerides	<0.001	<0.001	0.002
Glucose	<0.001	0.035	0.115
HDL cholesterol	0.008	<0.001	<0.001
Waist	0.001	<0.001	0.021

Note: P-values are from the interaction terms with age. All of the models also included controls for the other two factors that were not the interaction.

The previous descriptions are based on a visual assessment of the similarity of model-based estimates of the associations of biomarkers with age from birth and with age to death. Table 2 presents p-values of the interaction terms between age and gender, place, and education in order to test whether there are statistically significant differences in the association between biomarkers and age by gender, place, and education. The only two biomarkers for which no clear interaction with gender are found are for BMI, CRP, and total cholesterol. For all of the other biomarkers, the relationship between age differs markedly by gender. For place, only CRP and total cholesterol does not differ; all of the other interactions between place and age have p-values consistent with an interaction. For education, CRP and glucose do not differ. Overall, these differences are much more numerous than would be expected by chance.

Table 3 shows the strength of the non-linear relationships between all biomarkers and age based on the results of a single regression model for each country. The relative strength of the association, conditional on all of the other biomarkers in the model, could be assessed with the F-statistic within each model. Much more of the variance in age is explained in Costa Rica (59%) than in the United States (28%).

Tables 4 and 5 show the same relationships, but stratified by gender and level of education, respectively. The amount of variance explained is similar for women (34%) and for men (29%) (Table 4). More variance in age is explained for

Table 3:
Full model of biomarkers predicting age in Costa Rica and in the United States

	Costa Rica			United States		
	edf	**F-stat**	**p-value**	**edf**	**F-stat**	**p-value**
Diastolic	8.8	40	<0.001	7.4	8.4	<0.001
Systolic	6.9	51	<0.001	5.4	6.6	<0.001
Total Cholesterol	1.6	0.6	0.54	7.2	8.3	<0.001
BMI	8.7	63	<0.001	3.7	4.7	<0.001
Telomere length	8.7	110	<0.001	8.9	9.0	<0.001
HbA1c	5.2	6.2	<0.001	6.8	7.9	<0.001
Creatinine	3.0	9.4	<0.001	7.7	8.5	<0.001
CRP	7.8	15	<0.001	3.2	4.0	<0.001
Triglycerides	8.3	6.2	<0.001	7.5	8.5	<0.001
Glucose	8.0	6.8	<0.001	8.5	8.9	<0.001
HDL cholesterol	7.4	4.0	<0.001	5.9	7.2	<0.001
Waist	8.4	12	<0.001	8.2	8.8	<0.001
	R-sq.(adj) = 0.583			R-sq.(adj) = 0.273		
	Deviance explained = 59%			Deviance explained = 28%		

Note: edf is estimated degrees of freedom. Estimated degrees of freedom are based on penalized degrees of freedom from the spline model.

individuals with lower levels of education (38%) than for individuals with higher levels of education (27%).

4 Discussion

Our analyses examined how 12 potential biomarkers of aging are correlated with age in terms of both the number of years since birth and the number of years until death. The first minimal criterion we used to determine whether each of these biomarkers should be considered a universal biomarker of aging was a test of whether the biomarker was correlated with age; i.e., whether the physiological levels of the biomarker deteriorated with age. Out of the 12 biomarkers tested, only four met this criterion: namely, systolic blood pressure, C-reactive protein, HDL cholesterol, and telomere length. The second minimal criterion that we tested for each of these biomarkers was whether the sign of this correlation was consistent across genders, countries, and levels of education. None of the biomarkers we examined both worsened with age and were consistent across these groups. The results were similar when we examined both age since birth and thanatological age, although two factors met our minimal criteria using thanatological age: namely, CRP and HDL cholesterol. We therefore conclude that of the biological and anthropometric

Table 4:
Full model of biomarkers predicting age by gender

	Women			Men		
	edf	**F-stat**	**p-value**	**edf**	**F-stat**	**p-value**
Diastolic	8.8	29	<0.001	8.8	31	<0.001
Systolic	8.3	63	<0.001	6.5	43	<0.001
Total Cholesterol	5.6	8.9	<0.001	5.2	3.6	0.001
BMI	4.9	140	<0.001	7.5	53	<0.001
Telomere length	8.8	54	<0.001	8.9	38	<0.001
HbA1c	8.1	5.5	<0.001	6.0	6.6	<0.001
Creatinine	6.5	28	<0.001	4.3	22	<0.001
CRP	3.3	4.1	0.002	5.0	11	<0.001
Triglycerides	5.7	8.5	<0.001	6.6	12	<0.001
Glucose	8.5	13	<0.001	6.7	2.5	0.009
HDL cholesterol	7.1	9.3	<0.001	7.8	7.0	<0.001
Waist	8.48	21	<0.001	5.2	13	<0.001
	R-sq.(adj) = 0.335			R-sq.(adj) = 0.288		
	Deviance explained = 34%			Deviance explained = 29%		

Note: edf is estimated degrees of freedom. Estimated degrees of freedom are based on penalized degrees of freedom from the spline model.

measures that we examined here, and which have been shown to be associated with mortality, none fit our criteria for being considered a biomarker of aging; i.e., none of these measures were shown to both worsen with age and display consistency across genders, countries, and educational groups. The main contribution of our analysis is that it serves as a population-based demographic complement to research on biomarkers of aging conducted in individual-based physiological studies, animal studies, and *in vitro* studies. Our results suggest that it is critical to examine whether both individual and composite measures of aging are predictive of age, not just in the overall population, but in subsets of the population and in different countries.

Our analysis has several limitations. The most important of these limitations is that we were constrained in the number and in the types of biomarkers we were able to examine by data availability. While two of the three datasets (CRELES and HRS) were specifically focused on aging, the limited availability of other types of biomarkers in the HRS and the NHANES samples precluded their inclusion. This is an important limitation to consider when looking at our results in relation to the findings of other studies, as a number of factors – including IL-6, DHEA, and norepinephrine – that have been used in indices of biomarkers of aging (Gruenewald, Seeman, Ryff, Karlamangla and Singer 2006; Johnson 2006) could not be included in our analysis. Yet despite these drawbacks, an advantage of our selection of biomarkers is that each of these biomarkers clearly meets the criterion of being a

Table 5:
Full model of biomarkers predicting age by education

	Low education			High education		
	edf	**F-stat**	**p-value**	**edf**	**F-stat**	**p-value**
Diastolic	8.8	38	<0.001	5.5	51	<0.001
Systolic	8.2	46	<0.001	5.2	82	<0.001
Total Cholesterol	4.9	4.4	<0.001	6.0	6.0	<0.001
BMI	5.2	110	<0.001	6.7	57	<0.001
Telomere	8.8	62	<0.001	8.9	46	<0.001
HbA1c	4.5	4.4	<0.001	2.6	4.1	0.006
Creatinine	5.0	29	<0.001	7.0	34	<0.001
CRP	5.5	6.4	<0.001	1.9	0.4	0.567
Triglycerides	4.5	16	<0.001	8.1	4.0	<0.001
Glucose	7.8	2.9	0.002	7.9	26	<0.001
HDL cholesterol	4.9	5.4	<0.001	5.3	6.9	<0.001
Waist	8.1	11	<0.001	7.8	15	<0.001
	R-sq.(adj) = 0.375			R-sq.(adj) = 0.267		
	Deviance explained = 38%			Deviance explained = 27%		

Note: edf is estimated degrees of freedom. Estimated degrees of freedom are based on penalized degrees of freedom from the spline model.

precursor to chronic disease risk, rather than a consequence of disease. However, the question of whether biomarkers of aging need to be associated with mortality itself remains open. Opinions on this issue differ depending on which definition of biomarker of aging is being used. Another limitation of this analysis is that in our calculation of thanatological age, the range was limited by the amount of follow-up time. Thus, we were able to examine this relationship over a fairly short time span only; i.e., over a period of up to seven years. A further limitation is that we did not account for selection out of the sample due to mortality. The associations with age that we examined may have been affected by the possibility that individuals whose biomarker values worsened with age were more likely to die, and were therefore not represented in our samples. We note, however, that we were able to examine the extent to which this was occurring by fitting non-linear models, and did not observe any general patterns of weakening relationships with age. Nevertheless, it is important to keep in mind that our findings apply only to people aged 60 and older, and that the relationships among people under age 60 may be different, and highly relevant to identifying biomarkers of aging.

Our results appear to support some recent reports in the literature that cast doubt on the possibility of identifying universal biomarkers of aging (Johnson 2006). They are also in line with the findings of other studies indicating that demographic patterns of biomarkers may vary by country context. For example, while a large number of studies have shown that HDL cholesterol is higher in women than men, more detailed analyses have shown that the size of this gender gap differs by country, with the gap being very large in some countries and almost undetectable in others (Davis et al. 1996). The conclusions of the current analysis are also similar to the findings of prior work showing that the associations between biomarkers and educational levels differ between the U.S. and Costa Rica (Rehkopf, Dow and Rosero-Bixby 2010). In some cases, it has been shown that relationships between biomarkers and factors such as age, gender, and socioeconomic position that appear to be consistent are actually context-dependent, or are not robust to examination when samples from other countries are used. Telomere length represents a particularly striking example of this context dependence. While it is one of the more consistent biomarkers we examined, we still found differences in the relationship with age by gender, and striking non-linear relationships with age, particularly among less educated women in the U.S. The reasons for these and other heterogeneous associations with age should be further investigated in future work.

While we did not find any specific biomarkers that consistently worsened with age across groups, we did find that in our overall models a substantial amount of variation in age was explained: i.e., more than 25%, and up to nearly 60% in Costa Rica. This result is consistent with the observation made by a number of scholars that aggregated indexes of biomarkers may be useful for measuring aging (Der et al. 2012; Gruenewald et al. 2006). However, based on our analysis of changes in individual biomarkers with age, it appears that a relatively large portion of the explained variance is attributable to associations that may be in a direction that is the opposite of the one we expected. Of particular interest is our observation that the associations with thanatological age in the years immediately prior to death differed from the associations with age from birth, as this finding suggests that some of these biomarker relationships may be due to physiological changes that occurred close to death, and may thus have been caused by chronic disease processes. While the scope of our data limits our ability to speculate about this possibility, our findings provide further support for the claim that these factors should not be considered biomarkers of aging. More generally, additional study is needed to answer the question of why these associations exist, and to determine the extent to which these associations are attributable to selection out of the sample due to the deaths of individuals with relatively poor biomarker values, or to more intense medical management of diseases.

Our findings suggest that a number of factors that have been shown to be associated with mortality are not universal biomarkers of aging, especially if we use as our criteria for determining whether they are biomarkers of aging not just whether they are correlated with age, but whether they become more deleterious with age. In light of findings for other measures, such as functional status, grip strength, self-reported health, and walking speed, we may discover that measures that are less specific to a single physiological system are more useful than risk factors for chronic diseases for measuring the aging process.

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References

Arking, R. 2006. *Biology of aging: observations and principles* (Vol. 7): Oxford University Press New York.

Baker, G. T., 3rd and R. L. Sprott 1988. Biomarkers of aging. *Experimental gerontology* 23(4-5): 223–239. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3058488.

Belsky, D. W., A. Caspi, R. Houts, H. J. Cohen, D. L. Corcoran, A. Danese, T. E. Moffitt 2015. Quantification of biological aging in young adults. *Proc Natl Acad Sci USA* 112(30): E4104–4110. doi:10.1073/pnas.1506264112.

Boonekamp, J. J., M. J. Simons, L. Hemerik and S. Verhulst 2013. Telomere length behaves as biomarker of somatic redundancy rather than biological age. *Aging cell* 12(2): 330–332. doi:10.1111/acel.12050.

Butler, R. N., R. Sprott, H. Warner, J. Bland, R. Feuers, M. Forster and M. Hyman 2004. Aging: the reality biomarkers of aging: from primitive organisms to humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 59(6): B560–B567.

Cawthon, R. M. 2002. Telomere measurement by quantitative PCR. *Nucleic Acids Res* 30(10): e47. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12000852.

Crimmins, E., S. Vasunilashorn, J. K. Kim and D. Alley 2008. Biomarkers related to aging in human populations. *Adv Clin Chem* 46: 161–216.

Davis, C., D. Williams, R. Oganov, S.-C. Tao, S. Rywik, Y. Stein and J. Little 1996. Sex difference in high density lipoprotein cholesterol in six countries. *American Journal of Epidemiology* 143(11): 1100–1106.

Der, G., G. D. Batty, M. Benzeval, I. J. Deary, M. J. Green, L. McGlynn, P. G. Shiels 2012. Is telomere length a biomarker for aging: cross-sectional evidence from the west of Scotland? *PLoS One* 7(9), e45166. doi:10.1371/journal.pone.0045166.

Gruenewald, T. L., T. E. Seeman, C. D. Ryff, A. S. Karlamangla and B. H. Singer 2006. Combinations of biomarkers predictive of later life mortality. *Proc Natl Acad Sci USA* 103(38): 14158–14163. doi:0606215103 [pii] 10.1073/pnas.0606215103.

Ingram, D. K., E. Nakamura, D. Smucny, G. S. Roth and M. A. Lane 2001. Strategy for identifying biomarkers of aging in long-lived species. *Experimental Gerontology* 36(7): 1025–1034.

Johnson, T. E. 2006. Recent results: biomarkers of aging. *Experimental Gerontology* 41(12): 1243–1246.

Juster, F. T. and R. Suzman 1995. An overview of the health and retirement study. *Journal of Human Resources* 30: S7–S56. doi:Doi 10.2307/146277.

Karlamangla, A. S., B. H. Singer, B. S. McEwen, J. W. Rowe and T. E. Seeman 2002. Allostatic load as a predictor of functional decline: MacArthur studies of successful aging. *Journal of Clinical Epidemiology* 55(7), 696–710.

Karlamangla, A. S., B. H. Singer and T. E. Seeman 2006. Reduction in allostatic load in older adults is associated with lower all-cause mortality risk: MacArthur studies of successful aging. *Psychosomatic Medicine* 68(3): 500–507.

Krieger, N. 2005. Embodiment: a conceptual glossary for epidemiology. *Journal of Epidemiology and Community Health* 59(5): 350–355.

Levine, M. E. 2013. Modeling the rate of senescence: can estimated biological age predict mortality more accurately than chronological age? *J Gerontol A Biol Sci Med Sci* 68(6): 667–674. doi:10.1093/gerona/gls233.

Mather, K. A., A. F. Jorm, R. A. Parslow and H. Christensen 2011. Is telomere length a biomarker of aging? A review. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences* 66(2): 202–213. doi:10.1093/gerona/glq180.

Nadon, N. L. 2006. Of mice and monkeys: National Institute on Aging resources supporting the use of animal models in biogerontology research. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 61(8): 813–815.

NCHS 1999. National Health and Nutrition Examination Survey. Retrieved from http://wwwn.cdc.gov/nchs/nhanes/search/nhanes99_00.aspx.

Needham, B. L., N. Adler, S. Gregorich, D. Rehkopf, J. Lin, E. H. Blackburn and E. S. Epel 2013. Socioeconomic status, health behavior, and leukocyte telomere length in the National Health and Nutrition Examination Survey, 1999-2002. *Soc Sci Med* 85, 1–8. doi:10.1016/j.socscimed.2013.02.023.

RAND 2011. *HRS Data, Version L, Produced by the RAND Center for the Study of Aging, with funding from the National Institute on Aging and the Social Security Administration*.

Rehkopf, D. H., W. H. Dow and L. Rosero-Bixby 2010. Differences in the association of cardiovascular risk factors with education: a comparison of Costa Rica (CRELES) and the USA (NHANES). *Journal of Epidemiology and Community Health* 64, 821–828. doi: 10.1136/jech.2009.086926.

Rehkopf, D. H., W. H. Dow, L. Rosero-Bixby, J. Lin, E. S. Epel and E. H. Blackburn 2014. Seasonal variation of peripheral blood leukocyte telomere length in Costa Rica: A population-based observational study. *American Journal of Human Biology: the Official Journal of the Human Biology Council* 26(3): 367–375. doi: 10.1002/ajhb.22529.

Ridker, P. M. 2003. Clinical application of C-reactive protein for cardiovascular disease detection and prevention. *Circulation* 107(3): 363–369.

Riffe, T. 2015. The force of mortality by life lived is the force of increment by life left in stationary populations. *Demogr Res* 32: 827.

Rogot, E., M. Feinleib, K. A. Ockay, S. H. Schwartz, R. Bilgrad and J. E. Patterson 1983. On the feasibility of linking census samples to the National Death Index for epidemiologic studies: a progress report. *American Journal of Public Health* 73: 1265–1269.

Rosero Bixby, L., X. Fernandez and W. H. Dow 2010. *CRELES: Costa Rican Longevity and Healthy Aging Study, 2005 (Costa Rica Estudio de Longevidad y Envejecimiento Saludable: Sampling and Methods No. ICPSR26681-v2*.

Rosero-Bixby, L. and W. H. Dow 2012. Predicting mortality with biomarkers: a population-based prospective cohort study for elderly Costa Ricans. *Population Health Metrics* 10(11): 1–15.

Sanders, J. L. and A. B. Newman 2013. Telomere length in epidemiology: a biomarker of aging, age-related disease, both, or neither? *Epidemiologic Reviews* 35(1): 112–131.

Seeman, T. E., B. S. McEwen, J. W. Rowe and B. H. Singer 2001. Allostatic load as a marker of cumulative biological risk: MacArthur studies of successful aging. *Proceedings of the National Academy of Sciences* 98(8): 4770–4775.

Steel, D. M. and A. S. Whitehead 1994. The major acute phase reactants: C-reactive protein, serum amyloid P component and serum amyloid A protein. *Immunology Today* 15(2), 81–88.

Stekhoven, D. J. and P. Bühlmann 2012. MissForest—non-parametric missing value imputation for mixed-type data. *Bioinformatics* 28(1): 112–118.

Waljee, A. K., A. Mukherjee, A. G. Singal, Y. Zhang, J. Warren, U. Balis and P. D. Higgins 2013. Comparison of imputation methods for missing laboratory data in medicine. *BMJ Open* 3(8): e002847. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3733317/pdf/bmjopen-2013-002847.pdf.

Weinstein, M., J. W. Vaupel, K. W. Wachter and D. Weir 2008. Elastic powers: The integration of biomarkers into the Health and Retirement Study.

Wood, S. 2006. *Generalized Additive Models: An Introduction with R*. Boca Raton: Chapman & Hall/CRC.

Zahn, J. M., S. Poosala, A. B. Owen, D. K. Ingram, A. Lustig, A. Carter and K. Mazan-Mamczarz 2007. AGEMAP: a gene expression database for aging in mice. *PLoS Genetics* 3(11): e201.