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Research Article

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Table of Contents

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Abstract

BACKGROUND
In low mortality countries, assessing future ageing depends to a large extent on scenarios of future mortality reduction at old age. Often in population projections mortality reduction is implemented via life expectancy increases that do not specify mortality change at specific age groups. The selection of models that translate life expectancy into age-specific mortality rates may be of great importance for projecting the older age groups of future populations and indicators of ageing.

OBJECTIVE
We quantify how the selection of mortality models, assuming similar life expectancy scenarios, affects projected indices of population ageing.

METHOD
Using the cohort-component method, we project the populations of Italy, Japan, Russia, Sweden, and the USA. For each country, the given scenario of life expectancy at birth is translated into age-specific death rates by applying four alternative mortality models (variants of extrapolations of the log-mortality rates, the Brass relational model, and the Bongaarts shifting model). The models are contrasted according to their produced future age-specific mortality rates, population age composition, life expectancy at age 65, age at remaining life expectancy 15 years, and conventional and prospective old-age dependency ratios.

CONCLUSIONS
We show strong differences between the alternative mortality models in terms of mortality age pattern and ageing indicators. Researchers of population ageing should be

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as careful about their choice of model of age patterns of future mortality as about scenarios of future life expectancy. The simultaneous extrapolation of age-specific death rates may be a better alternative to projecting life expectancy first and then deriving the age patterns of mortality in the second step.

1. Introduction

Projecting mortality is a crucial first step in studying the prospects of population ageing and its consequences. As life expectancy increases and population-ageing speeds up worldwide (Lutz et al. 2008), a considerable effort is being made to expand the methodology of mortality projection (Booth and Tickle 2008; Ediev 2011; Lee and Carter 1992; Mayhew and Smith 2013; Pollard 1987; Raftery et al. 2012; Stoeldraijer et al. 2013). However, authors rarely pay attention to the importance of choosing mortality models and their implications for assessing future population size and composition, and consequently indicators of population ageing.

Even though many scientists have demonstrated crucial differences between mortality scenarios in terms of life expectancy at birth (often a scenario variable in population projections) and predicted death rates (Bell 1997; Benjamin and Soliman 1993; Cairns et al. 2011; Janssen and Kunst 2007; Pollard 1987; Shang et al. 2011; Stoeldraijer et al. 2013) the impact on projected population ageing is rarely studied. An infinite number of age-specific mortality patterns – with potentially different consequences for population ageing – may produce the same trajectory of life expectancy at birth.

A note is due here on existing approaches to projecting age-specific mortality. Often, projections rely on a single input parameter, typically life expectancy at birth, to describe future mortality scenarios, and then derive details of mortality by age and sex using a proper model. Partly this is done because of convenience in describing future scenarios. Another reason for applying the top-down approach comes from the observations that (linear) trends in life expectancy provide better fit compared to models for age-specific (log) mortality (Lee 2003; White 2002; see also Oeppen and Vaupel 2002 on a related matter). A widespread approach is extrapolating the age-specific trends in mortality rates despite its mentioned limitation. The Lee-Carter model is one of the best-known extrapolation methods. It relies on a singular-value decomposition (SVD) of age-specific log-mortality rates by age-time (different options exist for sex and regional trends) in order to determine the general time trend and age-time interactions (Lee and Carter 1992). The model is convenient for producing stochastic mortality forecasts, although it is also widely used in deterministic projections. A particular limitation of the method is its potential to generate implausible (non-monotone at old age) age patterns of future mortality, but this drawback may be mitigated by either using the life expectancy produced by the model as an input for another model (the approach was once adopted by the U.S. Census Bureau, although currently the Bureau is back to the life expectancy extrapolation method), or by applying adjustments to the model parameters to avoid implausible age patterns (Ediev 2007; a similar model of 'robust rotation' is used by the UN team to improve the model performance at old age, Sevcikova et al. 2015). Direct linear extrapolation of age-specific log-mortality rates (Ediev 2008) is similar to the Lee-Carter method in dealing with disaggregated mortality, yet it differs in producing age-specific time trends based on data periods of different duration at different ages (which would not be possible to combine with the SVD used in the Lee-Carter method), and in using simpler computational procedures. It is also supplemented by a special adjustment procedure to avoid implausible age patterns in the projected mortality.

The target mortality approach, which assumes convergence of the age pattern of the death rates to a specified target, is somewhat similar to the extrapolative methods in assuming age-specific trends that are not produced using statistical procedures applied to the past data but rather are imposed by assumption. The third domain comprises parametric models used to describe and project the age profile of mortality rates. These include, in particular, Gompertz, Brass, Heligman-Pollard, and logistic models (Brass 1971a; Gompertz 1825; Heligman and Pollard 1980; Thatcher et al. 1998). The parametric models are convenient for producing, by design, plausible age patterns of mortality and reducing the age variation to a few parameters that may be easier to project. In practice, the above-described methods are used in different combinations: one method is used to produce scenarios for life expectancy at birth and another method is used to disaggregate that scenario into mortality by age-sex. For more detailed reviews of the mortality models see Booth and Tickle (2008) and Ishii (2014), and Stoeldraijer et al. (2013) for a more recent review of current practices in Europe.

Our focus here is on the second step of usual practice: we examine if (and by how much) varying mortality models, assuming exactly the same scenario for life expectancy at birth, yield substantially different results in terms of population ageing indicators. Because the mortality level at younger ages in developed countries is already very low and may have only very limited impact on projected population ageing, we focus on mortality at middle ages and above. For our purposes, it is not necessary to cover the (indefinite) entire set of mortality models. Instead, we consider four models that cover the entire range of possible model behavior at old age. We consider, in particular, the popular Lee-Carter and the direct extrapolation methods. These two methods are expected to yield close results, and the point of applying both methods is to see if using the more elaborate Lee-Carter method adds substantially to the simpler direct extrapolation. We also consider the Brass relational model, which is extensively used in projection practices. It is, in several ways, more convenient than extrapolative methods, and represents the family of parametric models. All three models mentioned are known for not being able to reproduce well accelerating mortality decline at old and oldest old age. However, instead of applying adjustments to these models at old age as proposed in the literature (Ediev 2014; Sevcikova et al. 2015) we opt for supplementing the first three models by another one representing the opposite extreme of the range of mortality models. We add to our study the Bongaarts shifting model (Bongaarts 2005), which may be expected to overestimate the mortality decline at advanced age because of assuming an uncompromised mortality shift and complete neglect of mortality compression. We apply these four models to a set of countries of different age composition and mortality trends and examine if, and by how much, the models differ in resulting indicators of population ageing. We quantify the differences in the projected indicators of population ageing that result from using different mortality models by assuming the same future trends in life expectancy. In the next section we describe our data, projection scenarios, ageing indicators, and details of the four mortality models, followed by the results and discussion sections.

2. Data, methods, and mortality models

Throughout the paper we rely on data from the Human Mortality Database (University of California, Berkeley and Max Planck Institute for Demographic Research 2014). It contains both the time series of mortality rates that are necessary to feed the projection models and the baseline populations by age and sex that are necessary for population projections.

To project populations we use the common cohort-component method (Shryock and Siegel 1973), with age patterns of mortality rates produced with alternative mortality models (see more details of the alternatives below). However, our fertility, migration, and life expectancy assumptions are similar across alternative projections, which enables us to highlight the effects of mortality models alone. More specifically, we use scenarios from the recent population projections for European countries by the Wittgenstein Centre for Demography and Global Human Capital (VID 2014) and the recent update of the World Population Prospects (United Nations 2015), as outlined in Table 1. Italy, Japan, Russia, Sweden, and the USA were selected for comparative purposes, as these countries represent a range of countries advanced in ageing that are different in their epidemiological transition and have very different age compositions in the base year. These countries also differ substantially in the role of the demographic drivers of population ageing (fertility, migration, and mortality). Data for all these countries are readily available from the Human Mortality Database, which facilitates parameterizing mortality models.

Table 1: Scenarios for life expectancy at birth, total fertility, and net migration assumed in calculations (the same scenarios are applied in all models)

	Life Expectancy at Birth, years									
	Italy		Japan		Russia		Sweden		USA	
Year	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men
2013	85.6	80.3	86.6	80.1	75.7	64.3	83.8	80.0	81.3	76.6
2020	86.7	81.3	87.7	81.2	76.4	65.6	84.9	81.2	82.2	77.7
2030	88.8	83.4	89.1	82.6	78.5	68.7	86.9	83.2	83.4	79.5
2040	90.8	85.5	90.4	83.9	80.4	71.4	88.9	85.2	84.5	81.4
2050	92.8	87.5	91.6	85.2	82.3	74.0	90.9	87.2	85.6	83.0

	Total Fertility					Net Migration, 000s				
Year	Italy	Japan	Russia	Sweden	USA	Italy	Japan	Russia	Sweden	USA
2013	1.4	1.4	1.7	1.9	1.9	293	69	277	49	989
2020	1.5	1.5	1.6	2.0	1.9	144	48	250	44	1002
2030	1.6	1.6	1.5	2.0	1.91	148	50	261	45	1000
2040	1.6	1.7	1.6	2.0	1.92	150	50	267	45	998
2050	1.6	1.7	1.7	2.0	1.92	149	49	267	45	974

Sources: (VID 2014) for Italy, Russia and Sweden, (United Nations 2015) for Japan and the USA.

Note that the scenarios we used are optimistic in terms of life expectancy improvement. For Italy and Sweden the life expectancy scenarios are consistent with the linear growth of about two years per decade observed in the recent past (Oeppen and Vaupel 2002; White 2002). The expected improvement for Russia is even faster. For Japan and the USA, which are not part of the European Demographic Data Sheet, we use more moderate assumptions from the World Population Prospects.

Our purpose is not to examine the difference in mortality forecasts as such, but rather to see if mortality models yield different results in terms of population ageing indicators. To this end we calculated a set of indicators of mortality and population ageing to compare the implications of alternative mortality models for each country.

Our main indicator of population ageing is the old-age dependency ratio (OADR), a simple and the most-used indicator of population ageing. Its apparent simplicity, however, may be misleading, as the very notion of 'old' can be defined in different ways (Sanderson and Scherbov 2005, 2010, 2013). The conventional OADR is defined as the ratio of the number of people above the age of 65 years to the number of people between the ages 20 and 64:

$$\text{OADR} = \frac{\text{Number of people 65 years or older}}{\text{Number of people ages 20 to 64}}$$

In some cases the proportion of people aged 60 or older is used in the numerator, sometimes 15 is used as the lower bound of ages in the denominator, or the ratio can be multiplied by 100; but whatever the age used as a threshold for being old, it is always considered fixed in time and space.

Following ideas of Ryder (1975), Sanderson and Scherbov (2005, 2010) have introduced the prospective old-age dependency ratio (POADR), where the threshold of being old is no longer fixed at age 65 but changes with the change in life expectancy. It is based on a constant remaining life expectancy and assumes that people are old when the average remaining life expectancy in their age group is less than 15 years:

$$\text{POADR} = \frac{\text{Number of people older than the old-age threshold}}{\text{Number of people aged between 20 and the old-age threshold}}$$

Regarding the mortality models, we have chosen variants of extrapolative models for the log-mortality rates, the Brass relational model and the Bongaarts shifting model, as explained in the introduction. Those models represent a wide range of possible mortality changes at older ages, from a very limited one as in the Brass relational model to a very strong one as in the Bongaarts shifting model. These models are briefly described below.

In the Lee-Carter (1992) model, the log-mortality rates at age x at time t are extrapolated as

$$\log(M(x,t))=A(x)+B(x)\cdot k_t$$

We apply no additional adjustments to the mortality level parameter k_t, estimate the model on the most recent thirty-years-long part of the data, and apply monotonicity adjustment to the estimated slopes $B(x)$ to avoid implausible (non-monotone at old age or with men having mortality lower than women) projected age patterns (Ediev 2007).

In the direct linear extrapolation model (Ediev 2008; see also Stoeldraijer et al. 2013; Wilson 2015):

$$\log(M(x,t))=A(x)+B(x)\cdot t$$

we apply monotonicity adjustment to the estimated slopes $B(x)$ to avoid implausible projected age patterns and estimate the model parameters based on the most recent age-specific periods of linearity in trends on log-mortality rates.

The Brass model (Brass 1971b) describes the logits of the life table probabilities to survive to age x:

$$\log((1\text{-}l(x,t))/l(x,t))=Alpha+Beta\cdot\log((1\text{-}l\cdot(x,t))/l^*(x,t))$$

(the standard probabilities are taken from a (smoothed) baseline life table for each of the populations).

The shifting model by Bongaarts (2005) implies for the old-age mortality (at ages 30 years and older):

$$M(x,t)= M(x\text{-}S(t),t_{baseline})$$

where $S(t)$ is the amount of age shift of the baseline profile that is necessary to produce the assumed life expectancy at birth (given its low levels, we assume no background mortality in the model). At ages younger than 30, where mortality is very low and has a minor effect in our study, we link the change in the death rates to that at age 30.

Any of these four models is compatible with practically any level of future life expectancy. In order to separate the effects of mortality models from the expected change in the overall level of mortality, we assume identical scenarios for life expectancy at birth in all models (Table 1). In the projection we fit the parameters of the models (mortality level k in the Lee-Carter model, time variable in the direct extrapolation model, mortality level coefficient *Alpha* in the Brass model, and the amount of age shift S in the Bongaarts model) to model the assumed life expectancy at birth.

The chosen mortality models, even if assuming similar e_0s, produce a very wide range of mortality forecasts at old age. Extrapolations of the age-specific rates (as in the direct extrapolation and Lee-Carter methods) tend to overlook the possibility of forthcoming accelerations of mortality decline at the oldest-old age. Similarly, compared to the baseline standard, the Brass model tends not to change the death rates at the oldest ages (Ediev 2014). The Bongaarts model, on the other hand, assumes pure (age) shift of old-age mortality and does not account for the compression of period mortality (Cheung et al. 2005; Cheung and Robine 2007; Ediev 2013a, 2013b; Fries 1980; Kannisto 2000; Tuljapurkar and Edwards 2011; Wilmoth and Horiuchi 1999), which results in possibly exaggerating mortality decline at the oldest-old ages.

Although differences between the selected models in terms of produced death rates are straightforward, the consequences for population ageing are not so obvious. This is because trends in ageing indicators reflect the combination of mortality changes with the underlying (and changing) population age composition. The prospective indicators also depend on a changing threshold of old age.

3. Results

Results of our exercises are provided in Table 2 and Figures 1 to 5.

Table 2: Selected numerical projection results for the year 2050 obtained with alternative projection methods for five countries

(Year 2050)			Method:			
Country	**Indicator**	**Sex**	**bong**	**brass**	**de**	**lc**
Italy	age_rle15	Men	78.0	75.9	76.3	76.3
		Women	82.4	80.5	80.9	81.0
	e(65)	Men	24.7	23.7	23.9	23.9
		Women	29.1	28.4	28.5	28.6
	oadr	Both sexes	0.727	0.714	0.713	0.714
	poadr	Both sexes	0.230	0.265	0.257	0.256
	pop_65+	Both sexes	21 008	20 749	20 711	20 722
	pop_90+	Both sexes	3 047	2 288	2 488	2 503
	pop_rle15	Both sexes	9 338	10 446	10 155	10 138

Table 2: (Continued)

(Year 2050)			Method:			
Country	**Indicator**	**Sex**	**bong**	**brass**	**de**	**lc**
Japan	age_rle15	Men	76.1	74.6	75.5	75.4
		Women	81.6	80.2	80.7	80.7
	e(65)	Men	22.9	22.1	22.6	22.6
		Women	28.3	27.7	27.9	27.9
	oadr	Both sexes	0.789	0.769	0.776	0.776
	poadr	Both sexes	0.265	0.287	0.275	0.275
	pop_65+	Both sexes	39 498	38 649	38 932	38 937
	pop_90+	Both sexes	6 022	4 748	5 372	5 379
	pop_rle15	Both sexes	18 744	19 832	19 211	19 216
Russia	age_rle15	Men	72.6	66.4		65.8
		Women	75.3	72.2		72.6
	e(65)	Men	19.0	15.3		14.9
		Women	22.2	20.2		20.1
	oadr	Both sexes	0.451	0.398		0.389
	poadr	Both sexes	0.199	0.254		0.252
	pop_65+	Both sexes	33 423	30 078		29 458
	pop_90+	Both sexes	2 897	1 179		1 670
	pop_rle15	Both sexes	17 840	21 419		21 138
Sweden	age_rle15	Men	77.5	75.5	75.6	75.6
		Women	80.5	78.8	79.0	78.9
	e(65)	Men	24.4	23.3	23.4	23.4
		Women	27.4	26.7	26.7	26.6
	oadr	Both sexes	0.448	0.436	0.435	0.435
	poadr	Both sexes	0.164	0.181	0.178	0.178
	pop_65+	Both sexes	2 972	2 912	2 905	2 902
	pop_90+	Both sexes	380	269	287	287
	pop_rle15	Both sexes	1 351	1 467	1 449	1 449

Table 2: (Continued)

(Year 2050)			Method:			
Country	**Indicator**	**Sex**	**bong**	**brass**	**de**	**lc**
USA	age_rle15	Men	76.3	73.8	74.0	74.2
		Women	77.3	75.9	75.2	75.8
	e(65)	Men	22.6	21.2	21.3	21.4
		Women	23.9	23.1	22.7	22.9
	oadr	Both sexes	0.411	0.394	0.391	0.393
	poadr	Both sexes	0.173	0.188	0.190	0.186
	pop_65+	Both sexes	87 826	84 867	84 103	84 590
	pop_90+	Both sexes	10 692	7 814	7 210	8 054
	pop_rle15	Both sexes	44 527	47 436	47 716	47 004

Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method. Indicators: age_rle15=age at remaining period life expectancy 15 years; e(65)=period life expectancy at age 65 (years); oadr=Old-Age Dependency Ratio; poadr=Prospective Old-Age Dependency Ratio; pop_65+=population of age 65 or older (thousands); pop_rle15=population of age with remaining life expectancy 15 years or older (thousands).

Projected age profiles of death rates. Not surprisingly, methods differ substantially in how they project the evolution of age-specific death rates (Figure 1). The Bongaarts' shifting model, which explicitly assumes age shifts in old-age mortality, is most optimistic in projecting a strong decline of mortality rates at ages 80 years and older (in the case of Russian males at an even younger age[4]). The extrapolation methods and the Brass model contrast to the Bongaarts' model in not assuming much change of mortality at oldest-old age (except for the case of Russian females, see note 1). Since all our extrapolations are based on the same scenario for life expectancy at birth, the Bongaarts' model also tends to be more pessimistic at young and middle old ages. Regarding differences at old age, the period life expectancy at age 65 shows method-to-method variation of about one year for Italy, Japan, Sweden, and the USA, and more than four and two years for Russian males and females respectively (Table 2, Figure 2). The shifting model is most optimistic and the other models' results are closer together; note, however, the more pronounced differences in the case of US women. These differences are of considerable importance for applications in pension systems and social welfare. The extraordinary difference in the case of Russia may be explained by

[4] In Russia the death rates have been unstable ever since the mid-20th century. They increased at adult ages before the 1980s, declined in the late 1980s, and have followed varying trends ever since. Because of the lack of consistent long-run trends, we decided not to use the direct extrapolation method in the Russian case. For the same reason, one should also be somewhat critical about the outcomes of the Lee-Carter method in the Russian case and not generalize the findings for Russia to other higher-mortality countries.

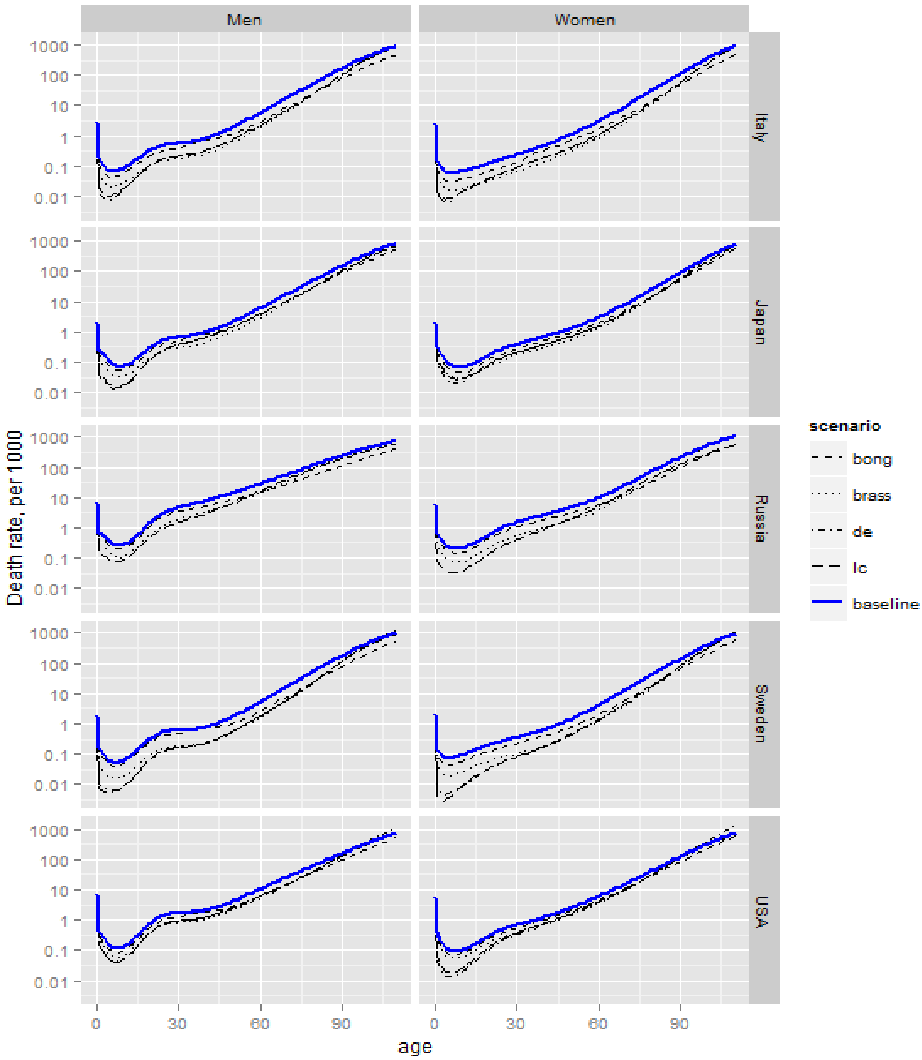
the combination of a rather optimistic underlying scenario for life expectancy at birth and the lack of mortality compression in the Bongaarts model. Variation at age when remaining life expectancy is 15 years or less (Table 2, Figure 3) also shows that the models have very different implications for old-age mortality (models differ by about 3–6 years for Russian women and men, and by 1.5–2.5 years for other populations). Taking this age as a threshold for defining who is old, about 54% of those Russian men who are ‘old’ in 2050 in the Lee-Carter model would still be ‘young’ in the Bongaarts shifting model. The difference would be smaller but still substantial for Russian women (27%) and for other countries (about 10%–20%).

Projected population age structure. While methods vary a lot in their projected old-age mortality, the effect of these differences on projected population age structure is more modest (Figure 4), except at advanced age. This is because on the one hand the mortality is very low at young age in all methods and on the other hand the number of people of old ages are relatively small in cohorts that are subject to the largest differences in projected mortality rates. Yet the Bongaarts’ shifting method is producing considerably more people at advanced ages (80-year-olds and older in 2050) and slightly fewer surviving population at younger ages than the other methods. This may have a sizable effect on the dependency ratios (see below). The Russian case, especially for men, is different in showing stronger differences also at younger ages. The models show large differences in the projected very old population (90-year-olds and older) in 2050: 30%–40% differences for all countries but Russia where the Bongaarts model produces more than two times very old people as compared to the Brass model. The Brass relational model happens to be the most conservative in terms of the very old population (with the exception of the USA). This might not be a mere coincidence, given the model’s lack of flexibility at advanced age (Ediev 2014).

As can be expected from the above results, OADR applying the conventional definition of ‘old’ (aged 65 years and more, the panel to the left in Figure 5) do not vary much from method to method for Sweden and Italy but show more cross-method variation for Russia. On the other hand, the Brass and the extrapolative methods do not show much difference even in the Russian case.

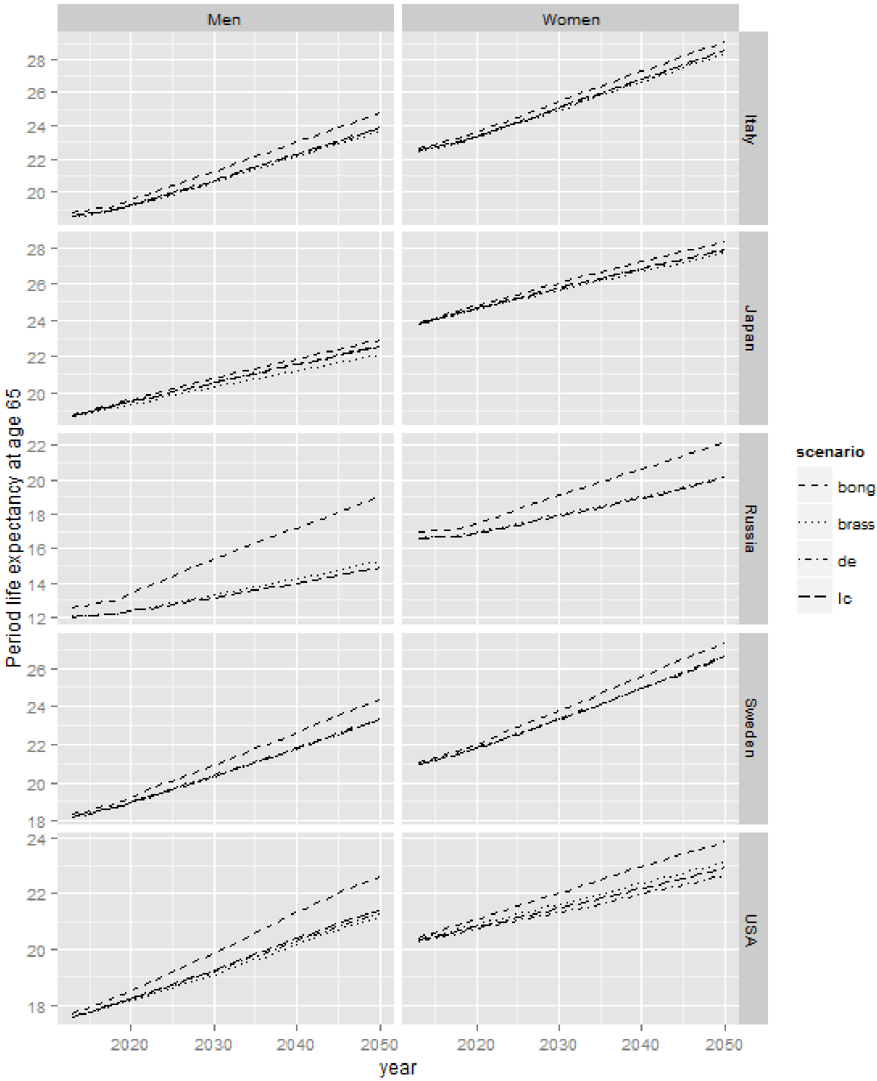
Because the models project steadily increasing age at remaining life expectancy of 15 years (with a different speed for different countries), patterns of POADR differ from those of the conventional OADR (the panel to the right in Figure 5). First, the POADR does not increase as much as the conventional ratio. For Russia and Sweden, the POADR shows almost no systematic increase in 2013–2050. Second, the methods differ more in the projected POADR. Third, the ranking of the methods also changes: the shifting model shows the lowest POADR, not the highest one as in the conventional case of projecting OADR. The case of Russia is, again, of highest cross-method variation.

Figure 1: Baseline (2013) and projected (2050) age-specific death rates, obtained with alternative projection methods for five countries



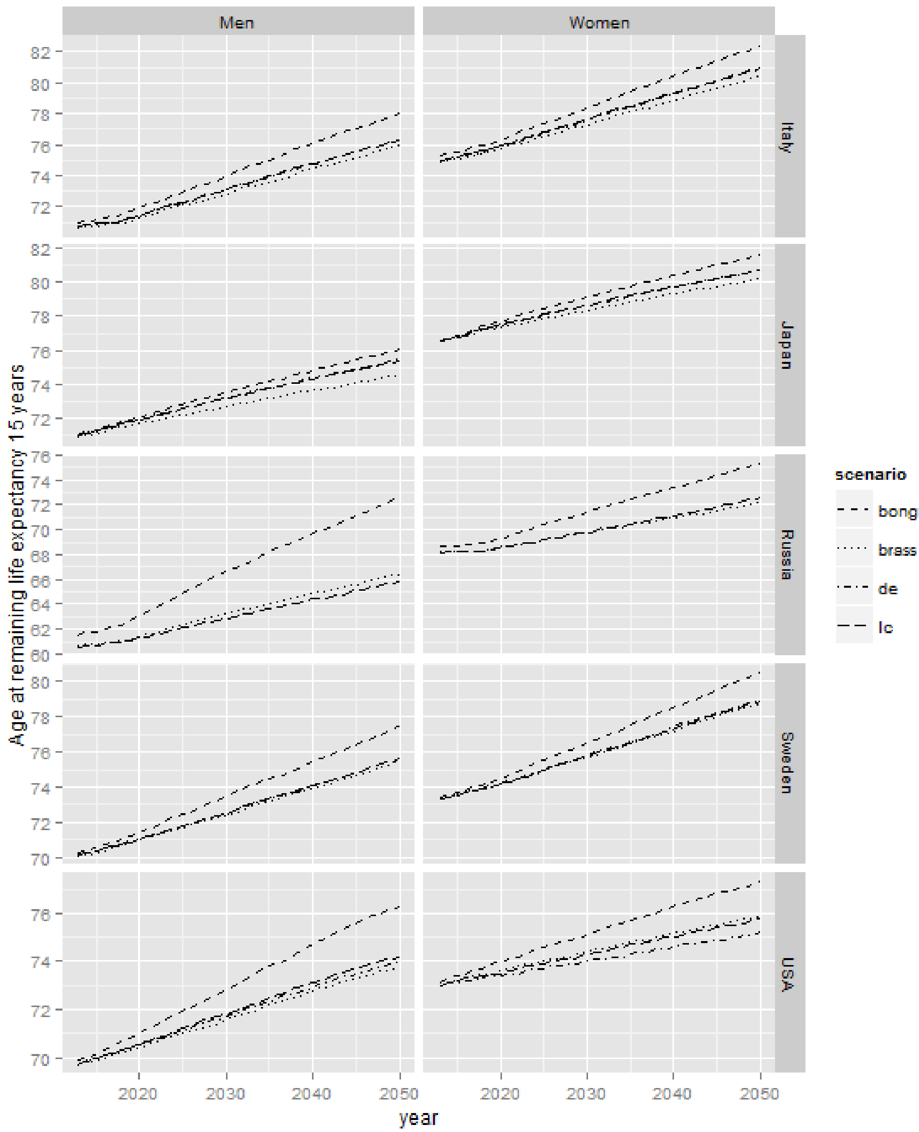
Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method; baseline=the profile of mortality rates in 2013 (obtained from the Bongaarts' model).

Figure 2: Projected period life expectancies at age 65, obtained with alternative projection methods for five countries



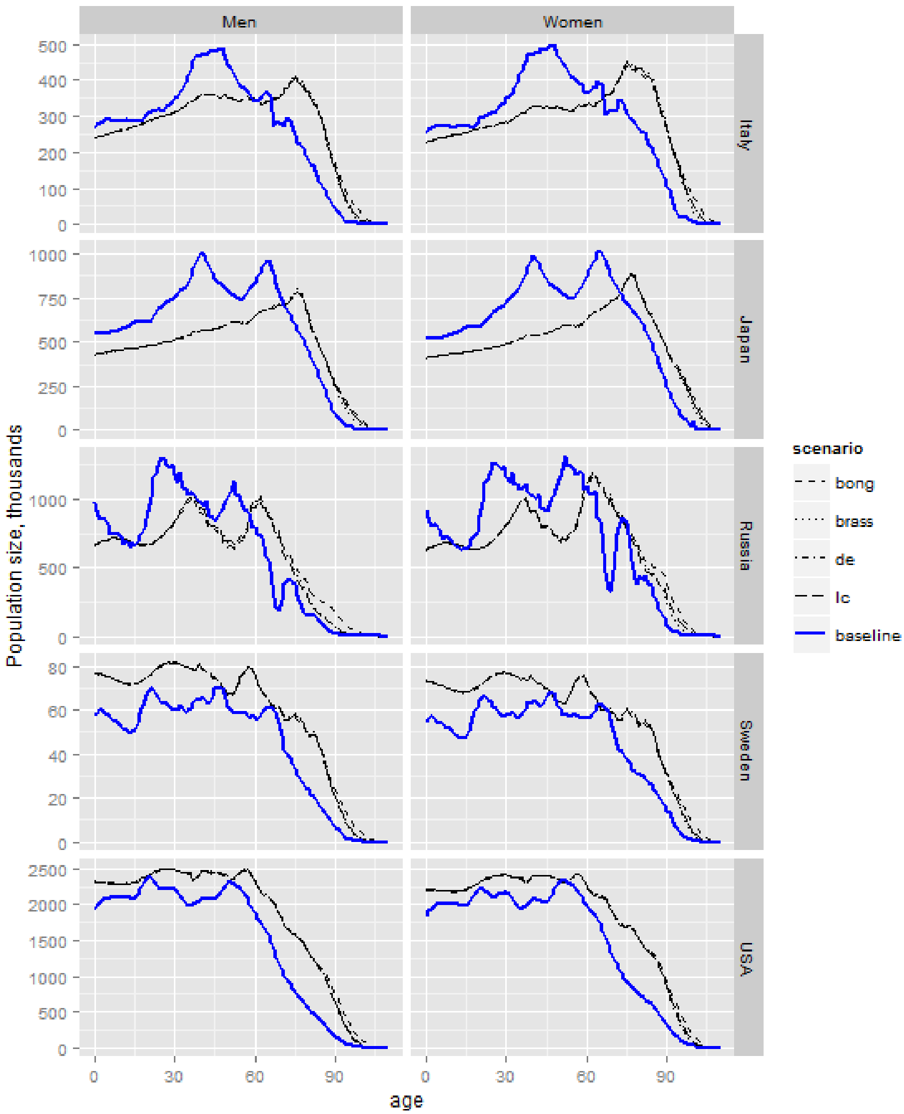
Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method.

Figure 3: Age at remaining life expectancy 15 years, projected with alternative projection methods for five countries



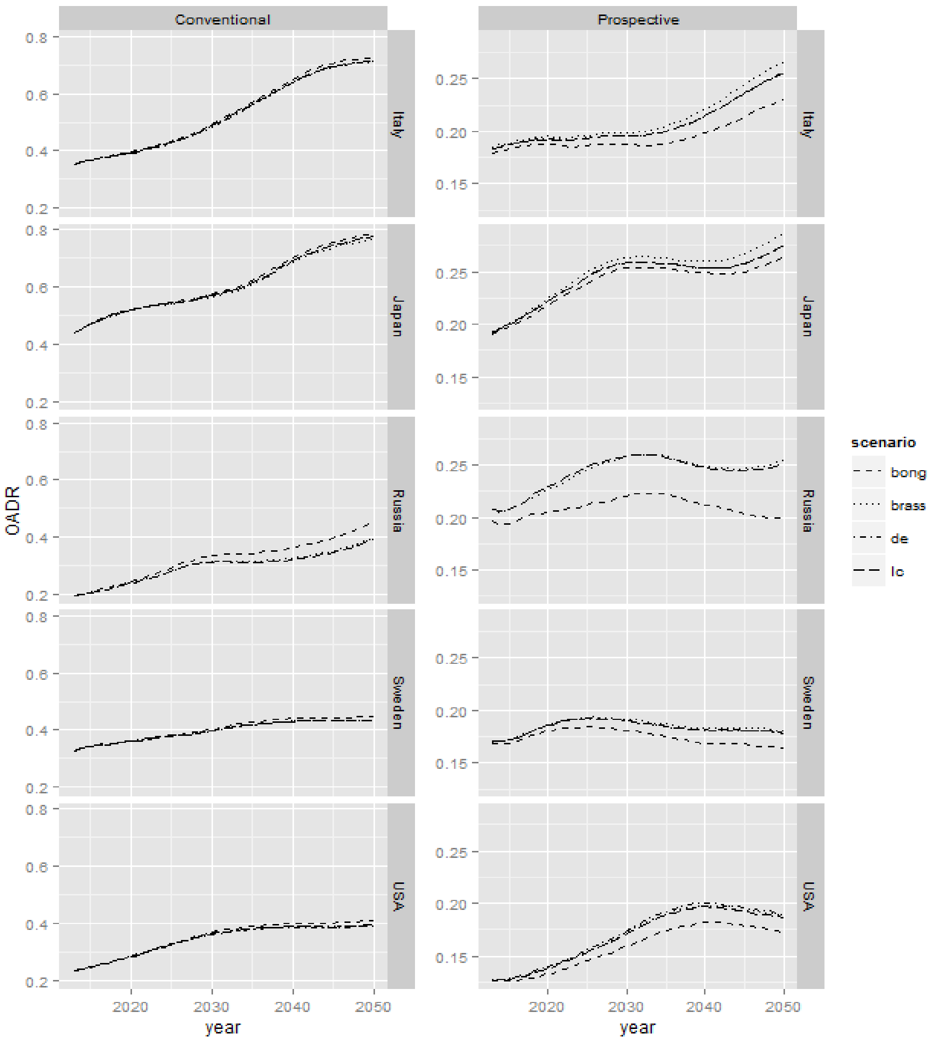
Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method.

Figure 4: Population age composition in 2050, projected with alternative projection methods for five countries



Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method; baseline=the profile of the year 2013.

Figure 5: Conventional and prospective old-age dependency ratio, projected with alternative projection methods for five countries



Methods: bong=Bongaarts' shifting model; brass=Brass model; de=direct extrapolation method; lc=Lee-Carter method. OADR: conventional=the ratio of the number of people 65 years or older to the number of people aged 20 through 64; prospective=the ratio of the number of people in the age groups with remaining life expectancy of 15 years or less to the number of people aged 20 through the first age group with remaining life expectancy of 15 years.

Patterns of the proportion old (conventional: aged 65 or older; prospective: with remaining life expectancy shorter than 15 years) are similar to those of OADR and POADR and therefore are not shown here.

4. Discussion

By and large, all four models agree in pointing to forthcoming increases in the number of people at older (in the conventional sense) age. Despite large systematic differences in projected age pattern of death rates and in the numbers of very old (90+) people, the models do not differ that much in terms of projected old (65+) population. The case of Russian males is an important exception. It has high baseline mortality and our scenario assumes fast increase of life expectancy at birth, which produces stronger relative differences in the projected population size at old age. However, even in the Russian case, the more optimistic Bongaarts model produces a conventional OADR not essentially different from the OADR in other models (0.45 vs about 0.40 by the year 2050, a relatively small difference when compared to the change from level 0.2 in the baseline year 2013). For lower-mortality Italy, Japan, Sweden, and the USA, with a more moderate pace of improvement in life expectancy at birth, the differences in OADR are even smaller.

Our projections also indicate that the prospective indicators of ageing will follow a path very different from that of the conventional indicators. In Italy, all methods produce only a limited increase in POADR, which will only speed up in 2030s (change from 0.18 in 2013 to 0.23–0.27, depending on the method, in 2050). In Japan, the POADR grows faster in the first decades. In Italy, Russia, and Japan, where there is low fertility, and in Japan, where there is low immigration, the POADR grows to the level 0.25 or higher, while Sweden and USA do not show a POADR exceeding 0.2. The difference between POADRs produced by the Bongaarts model and other alternatives is somewhat higher than between conventional OADRs in absolute terms and much higher in relative terms when compared to the expected change in the indicators. While yielding the highest OADRs, the Bongaarts model shows the lowest POADR in each of the country cases.

There is a substantial difference in method (specifically, between the Bongaarts and other three models) in terms of remaining life expectancy at age 65 and age at remaining life expectancy 15 years or less, which is considered to be the threshold of old age. Both indicators may be important for assessing the consequences of mortality decline for pension systems. Changes in life expectancy at age 65 may show roughly how large a pension obligation may accumulate in systems with rigid age at retirement, while age at remaining life expectancy of 15 years may indicate how much later people should retire in a system with a fixed amount of life-time pension obligation. The inter-method variation in these two indicators is especially wide (about four and six years, respectively, for remaining life expectancy at 65 and for age at remaining life expectancy 15 years in 2050) – due to assumed fast mortality decline – in the case of Russian males. It is also rather wide (about a year and a half or more) in other cases. As shown above, the number of those considered old according to the old-age threshold definition may differ considerably depending on which mortality model is selected.

The models appear to differ strongly in the projected very old (90+) population, which might be important for analysis of long-term care needs and acute health care need (both show strong increases by the late years of life, Fuchs 1984; Hogan et al. 2001; Lubitz et al. 2003; Miller 2001; Riley and Lubitz 2010).

To put our estimated differences into a context, Eurostat (European Commission 2014) mortality scenarios for Italy in 2050 assume an uncertainty range (between the main and the high life-expectancy scenarios) in life expectancy at age 65 of 1.3 years for men and 1.4 years for women. For Sweden, Eurostat produces uncertainty ranges of 1.2 (men) and 1.3 (women) years for the same indicator. These ranges are not much different from our model-to-model variation of 1.1 (men) and 0.7 (women) years for life expectancy at age 65 for both countries in 2050. Even in terms of OADR, where we found less of a difference between mortality models, Eurostat's scenario-to-scenario range in 2050 (0.024 for Italy and 0.018 for Sweden) is comparable to the range (0.013 for both countries) we obtained here. For Russia in 2030, the country statistical office (Federal State Statistics Service 2015) projects a high-to-low scenario range of OADR of 0.002 that is even narrower that our model-to-model range of 0.02 in the same year. Our projected model-to-model differences in old-age (65+) population numbers in 2050 are substantial when compared to the 80%-confidence intervals of the recent probabilistic UN projections (United Nations 2015). The inter-model differences exceed the half-confidence interval for Russia. For other countries, they constitute about 30%–50% of half-confidence intervals. We compare our results to the half-confidence intervals because the Brass and extrapolative models correspond to typical 'central' assumptions about old-age mortality, and the Bongaarts model serves here as a 'high' variant. If we compare our results to the confidence interval for the very old (90+) populations (not reported in the UN publication), the model-to-model variation would appear even more important. Model differences in terms of OADR also appear to be quite large when compared to the differences between the UN high (low) and medium variant projections: the former constitute 30%–80% of the UN range for the lower-mortality countries and more than double the UN range in the case of Russia.

Even though the Russian case may look like an outlier in our sample of countries, the large model-to-model differences shown for that country are an important indication that the role of mortality models may indeed become crucial for high-mortality and transition countries.

Our study suggests that projecting the whole age structure of the death rates – whenever feasible – should be preferred to projecting a single mortality index (such as life expectancy). Indeed, some of the works discussed in the introduction suggest that the latter approach appears to be inferior in prediction accuracy as compared to extrapolating life expectancy. This discrepancy may be attributed to the fact that most existing mortality extrapolation models miss important features of the actual mortality reduction process and need to be improved. Even if – for whatever reason – mortality projections do rely on projecting or scenario-building for a single mortality index, our results imply that the usual practice of not reporting the exact form of the model used to derive the age-specific mortality should be revised.

To answer the question posed in the title: yes, the selection of mortality model does make a difference in projecting population ageing. It may be as important as the selection of life expectancy scenario.

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