Distr.: General
30 March 2016

English only

Economic Commission for Europe

Conference of European Statisticians

Joint Eurostat/UNECE Work Session on Demographic Projections
Geneva, 18-20 April 2016
Item 2 of the provisional agenda
Methodology

Demographic determinants of population ageing in European countries

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Summary

For many countries, the major demographic concern is population ageing, not growth. There is a pressing need to understand the underlying demographic processes since policies to influence population ageing by stimulating both fertility and immigration have been advocated. Primacy has usually been given to fertility decline, based on stable population models and increasingly on use of population projections. However, Samuel Preston and co-authors have argued that improvements in cohort survivorship were the most important factor in high income countries and that mortality and fertility declines had similar impacts on population ageing in in low income ones. We discuss the basis of these estimates and potential explanations for apparently contradictory findings: the index of ageing differs; results to date are presented for recent narrow time periods that may be atypical; and whether these two approaches actually measure the same underlying concept.

We present long-run analyses of the relative contribution of cohort births, mortality and net migration to population ageing in two European countries, England & Wales and Sweden, using the method of Preston et. al.. We compare these findings with the main alternative approach that compares population projections with fixed and varying rates of fertility and mortality. Finally, we consider the role that international migration has played in population ageing and discuss the implications of these findings.

I. Introduction

1. Population ageing is a key feature of 21st century demographic trends. The Director of the UN Population Division, John Wilmoth, stated in 2015: “For many countries today, and probably for most countries in the long run, the major concern about their demographic situation will be in relation to population ageing, not growth” (Wilmoth, 2015a). United Nations projections suggest that by 2100 in most European countries, people aged 65 and over are expected to form over 30% of the population and one person in six will be aged 80 or over (United Nations Department of Economic and Social Affairs, 2015a). Europe is the region with the oldest population structure and there is a pressing need to understand the underlying processes since mortality is expected to continue to improve and policies to affect population ageing by stimulating both fertility and immigration have been advocated.

2. Population size and structure are determined by natural change - births minus deaths - and net migration. Mortality improvement has sometimes been presented as the plausible primary driver of long-term population ageing trends since it is the driver of individuals’ ageing. However, since the determinants of population ageing became a topic of study from the 1950s, (e.g. Valaoras, 1950; Coale, 1956; United Nations, 1956), primacy has usually been given to fertility decline: “one can say with every confidence of being correct that a lower course of fertility produces an older population than would a higher course, all other factors being the same; and with fair confidence that most mortality improvements in the past have produced a younger population than would have resulted from unchanged mortality” (Coale, 1956, p. 114). This conclusion remains the standard view; for example, John Wilmoth stated recently that: “Fertility decline is, by far, the most important cause of population ageing” (Wilmoth, 2015b).

3. Mortality improvement is increasingly recognised as a factor in population ageing, especially in low-fertility societies, a process sometimes referred to as ageing from the top as well as from the bottom, although as Ansley Coale above pointed out, historically its role was less substantial and the main effect has been to make population structures younger rather than older. The effect of migration on population ageing is generally regarded as minor in most situations (Goldstein, 2009).

4. The conclusion that fertility decline was historically the most important factor in population ageing in high income countries and remains so in low income ones is widely accepted. Both are consistent with a simplified demographic transition model. Fertility and mortality are initially broadly constant over time, and so populations will not age. With fertility decline, populations start to age, initially offset to some extent by mortality improvement being concentrated more at younger ages, both because it was easier to reduce mortality at these ages and this affected a large fraction of populations that were youthful. Mortality decline shifts later towards

improvement mainly at older ages and reinforces ageing. In high income countries when fertility had been relatively constant for an extended period of time and mortality improvement is concentrated at older ages, mortality change comes to dominate population ageing.

5. However, a different emphasis has been given by Samuel Preston and co-authors based on analysis by Horiuchi and Preston (1988). Preston, Himes and Eggers (1989) published analyses for changes in two developed countries in recent periods, US and Sweden, in period 1985-1990. They concluded that mortality improvement was the main driver of population ageing in this period. These analyses were based on an innovative model, referred to subsequently as the PHE model, that decomposes changes in population ageing between births, mortality and net migration; further details are given in the results section. Similar conclusions were reached by Caselli and Vallin (1990) looking at actual and projected population trends in France and Italy over period 1960-2040.

6. Preston and Stokes (2012, p. 231) using the PHE model to investigate sources of population ageing in the period 2005-10 concluded that: “in more developed countries, the massive improvements in survivorship from one birth cohort to the next have been the most important source of aging. Less developed countries have also enjoyed huge increases in survival from one cohort to the next, therefore the contribution of mortality and fertility declines were similar”. They attribute just over half, 51%, of population ageing in less-developed countries and over three quarters, 82%, in more developed countries (excluding Eastern Europe) to inter-cohort mortality change (Preston and Stokes, 2012, table 1).

7. We compare approaches to estimating the determinants of population ageing. The paper is organised as follows: we discuss the methods, data and assumptions that have been used to estimate the contribution of fertility, mortality and migration to population ageing in order to account for the apparently different conclusions reached. The approach of Preston, Himes and Eggars is applied over a long period to European countries, Sweden, for which data covers the whole experience as it passed through the demographic transition, and England & Wales that includes population projections up to 2113. We discuss the data are used, drawn from the Human Mortality Database for fitting the PHE model. The paper includes an assessment of the use of mean population age as an index of population ageing compared with alternative indicators. Finally, we explicitly consider the role that international migration has played in population ageing and discuss the implications of these findings for the future.

II. Methods for attributing population ageing to demographic components

Stable population models

8. Much of the initial analysis of the role of demographic determinants of ageing has been based on stable population models (e.g. United Nations, 1956; Coale, 1956). These simply show the population age distributions that would have been obtained if fertility and mortality had remained constant for a long period of time. A set of alternative models with fertility and mortality ranging over the typical values observed for human populations are presented. For example, Table 1, based on United Nations (1956), shows that the proportions aged 60 and over remain largely constant even with major changes in mortality with fertility fixed, whereas it changes substantially with changing fertility but fixed mortality. The artificial nature of this approach must be acknowledged, since no population experiences long-term fixed rates. Static models (i.e. with both constant fertility and mortality) are used to elucidate a dynamic process (since population ageing must include changing rates), and Nathan Keyfitz (1975) argued that such models were so far from reality that they provide little insight into the ageing process.

Gross reproduction rate (GRR)	Age group			Expectation of life at birth (e_0)	Age group		
	0-14	15-59	60 & over		0-14	15-59	60 & over
2.5	42.7	51.4	5.9	40	17.0	62.6	20.4
2.0	36.8	54.7	8.5	50	17.8	60.7	21.5
1.5	29.3	57.7	13.0	60.4	18.7	59.4	21.9
1.0	19.5	58.6	21.9	70.2	19.5	58.6	21.9

Table 1. Percent of population in age group with alternative demographic regimes

Notes: GRR panel based on e_0=70.2 & e_0 panel on GRR=1

Source: United Nations (1956), Tables 15 & 16.

9. The way population distributions alter as a population moves from one demographic regime to another are sometimes shown. However, the possible number of ways of moving between two models is arbitrarily large, so the major benefit of simplicity of Table 1 is lost. This is one reason why from an early stage, alternative scenarios from population projection models with realistic data have been used to investigate the effects of fertility and mortality on population ageing.

Counterfactual population projections

10. Use of counterfactual population projections as a method for assessing the contribution of demographic variables to population ageing hs been of

long-standing since this approach overcomes one of the main objections to the use of formal stable population models, that of unreality. They have been widely used to assess the implications of demographic patterns for population ageing over the past six decades (Valaoras, 1950; United Nations, 1956) not only for analysing fertility and mortality but also for the politically contentious issue of the role of migration in alleviating the impact of population ageing (United Nations Population Division, 2000). Over time, the availability of more detailed data and computer software has made this an increasingly attractive option. The Spectrum suite of policy related programs (http://www.avenirhealth.org/software-spectrum.php), which incorporates the complete set of data back to 1970 from the United Nations population projections, so enabling alternative projections from starting points from 1970 to be made later in this paper.

11. The standard approach is to compare the results obtained after controlling separately for the components of fertility, mortality and migration. This can include both projections made with a base year some decades in the past to compare with actual outturns and alternative scenarios including "realistic" projections assumed to be the most likely outcome. In most cases, the counterfactual is to fix fertility or mortality from the initial year and compare the outcomes under these alternative assumptions. Net migration is usually set to zero rather than the initial value. For assessing rate of population ageing, comparisons will typically use an index of ageing such as proportion of the total population aged 65 and over. Alternative scenarios with fixed fertility, fixed mortality and no migration are included among the variants in the latest United Nations 2015 Revision, together with "no change" variant, i.e. both fertility and mortality kept constant, (United Nations Department of Economic and Social Affairs, 2015b, pp. 31-2).

12. Much of the early work was concerned with the implications of change across the demographic transition, but more targeted analyses are required to analyse the relative contributions of fertility and mortality to population ageing in the post-transitional phase. Hermalin (1966) produced projections of the US age distribution across the 20th century including alternative scenarios of mortality, fertility and migration in the second part of the century. He showed that the 1960 US population was slightly younger than it would have been in the absence of 20th century mortality decline and – in particular – that mortality improvement was likely to be increasingly important in high income countries from the second half of the 20th century than it had been during the demographic transition.

The Preston, Himes and Eggars (PHE) method

13. The approach was developed in Preston, Himes and Eggars (1989) based on earlier work on age-specific growth rates (Horiuchi and Preston, 1988) arising from development of the Preston-Coale synthesis model (Preston and Coale, 1982). It has been used by Preston and Stokes (2012) in

both more and less developed country settings. Since the method may be unfamiliar and because the reasons for the differences in interpretation between this model and more conventional approaches depend on the model formulation, this will now be briefly described.

14. The decomposition allocates overall population changes over time into those due to fertility, mortality and migration as follows. The basic equation is

$$P(a,t) = B(t-a)exp\left(\int_0^a \{-\mu(x,t-x) + m(x,t-x)\}dx\right) \qquad 1.$$

Where *P(a,t)* is population aged *a* at time *t*
B(t) is number of births in year *t*
μ(a,t) is hazard rate of mortality at age *a* at time *t*
m(a,t) is net migration rate at age *a* at time *t*
taking logarithms and differentiating, we obtain

$$r(a,t) = \frac{\partial \ln\{P(a,t)\}}{\partial t} = \frac{\partial \ln\{B(t-a)\}}{\partial t} - \int_0^a \frac{\partial \mu(x,t-x)}{\partial t}dx + \int_0^a \frac{\partial m(x,t-x)}{\partial t}dx$$

Where *r(a,t)* is the age-specific rate of growth of population aged *a* at time *t*. The PHE model can be summarised by noting that the annual change in population numbers in a particular year at a given age is simply the difference at that age between numbers alive at the start and end of the period. The numbers alive are determined by the size of the birth cohort they are drawn from, with allowance for mortality and migration in the intervening period using eq. 1. This decomposes changes across time for the population aged *a* into changes in cohort births around *a* years ago, and in subsequent cohort survival and lifetime net migration. The contribution of changes in births, survival probability and net migration of adjacent cohorts to overall change in the period can therefore be uniquely allocated. Population ageing is measured by the difference in mean age of the population at the start and end of the year, which is equal to the value of these individual age-specific changes averaged over all ages.

15. Population ageing occurs when the population distribution shifts towards older ages, which may be measured by the first derivative of mean population age. Therefore period changes in population mean age can be decomposed into changes in three components, births, cohort survival and lifetime net migration. The last two are functions of age-specific mortality and net migration rates. However, the first component in this original model is based on number of births rather than fertility rates.

16. For analysis in year *T*, the population size at age *a* is determined by rates in the previous *a* years (to a maximum of 110 years in our case, although in practice the effective prior period is less if the proportion of the population at high ages is small), and the and the birth cohort size *a* years earlier. These birth cohort numbers are determined by earlier vital rates that can affect the current distribution, so ultimately on rates stretching back for unlimited periods in the past. In practice, more recent rates will smooth out earlier variation so that the current distribution is insensitive to rates more than a few generations earlier as shown by the strong and weak ergodicity theories (Arthur, 1982), although this also shows that more recent rates are highly influential and need to be included appropriately.

17. The calculation of mean population age in year *T* depends on the numbers in each age group, which is determined by the lifetime experience of all members of the cohort alive at that time, so it depends on rates and population sizes for up to a century or so earlier. High proportions surviving to older ages means that older groups therefore contribute substantially to trends in population ageing such as the mean age of the population. Therefore the lifetime experience of cohorts born around 80 years earlier will be influential, so that data requirements are substantial. However, the number of centenarians is small, so these cohorts contribute little to the estimates of mean ages. Rate values for periods more the hundred years do not contribute independently to the estimates of the components of population ageing, but only via the initial birth cohort numbers. While the model separates the influences of rates before and after *a* years ago for those aged *a*, this is not the complete answer for two reasons. The first is that the direct influence of mortality and migration rates includes periods between 0 to 110 years earlier that depend on the age of person concerned. The second is that the birth cohort size, which is a consequence of earlier rates, does not permit decomposition of the relative contribution of fertility, mortality and migration in these earlier periods without additional modelling. We discuss this further in the results section.

III. Results

The index of ageing used

18. The principal index of ageing differs between methods and we need to establish that this factor is not responsible for the difference between methods. Therefore we compare population mean age used by PHE with other more widely-used indicators of population ageing. Change in population mean age is not a commonly-used indicator of population ageing. Median age together with a number of alternative measures based on proportions of people over an age such as 65, or potential support ratios such as the ratio of nominal working age (e.g. 15-64) to nominally retired population (e.g. 65 & over) are more common and available for all countries from the projections of the United Nations Department of Economic and Social Affairs (2015a).

19. Although less widely used, the mean age has a central role in the PHE method. It has more general advantages as a summary statistic: it is sensitive to the value of every observation; it gives more weight to observations at the extremes of the age distribution; and it is directly linked to the wider set of statistical indicators such as covariance with age that arise in the formulation of the PHE model. The PHE method is centred on the mean age of the population as the primary indicator of population ageing, although it is possible to elaborate the model to incorporate alternative indicators of ageing. In contrast, the projections method is completely flexible and any option can be chosen.

20. Figure 1 shows that long-term time trends in these indicators are very similar and therefore mean age provides the same information on population ageing as the others, so use of alternative indicators does not explain the different interpretations of the determinants of population ageing.

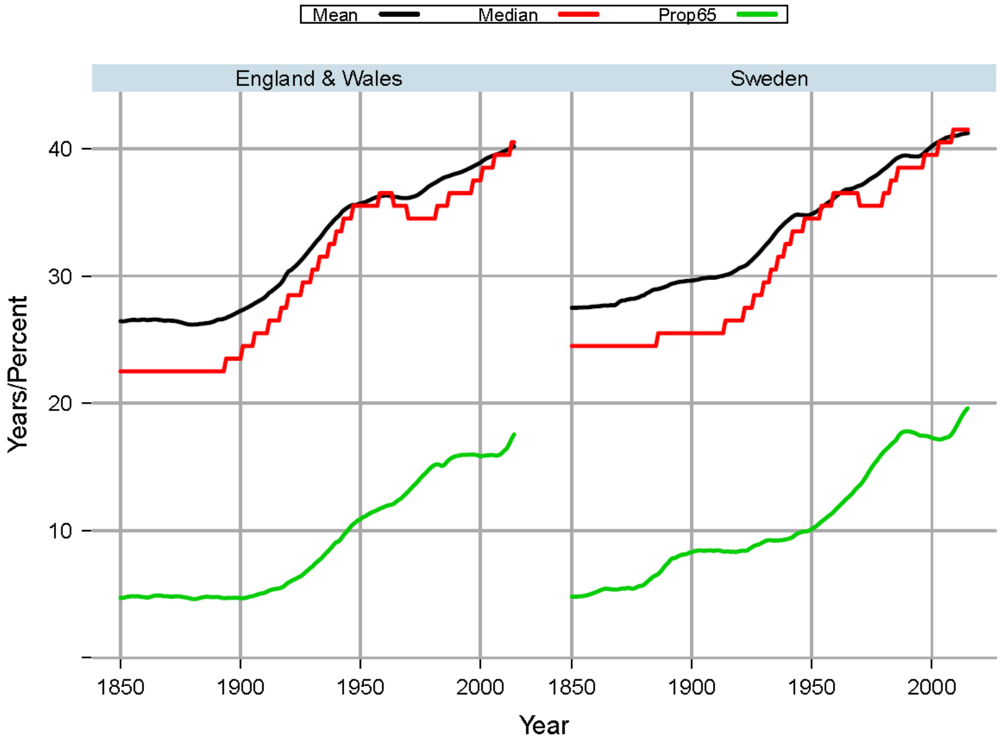

Figure 1. Alternative indicators of population ageing

Source: Human Mortality Database.

Sensitivity of estimates to data start year and time period covered

21. While generalised statements about the determinants of population ageing exist, the possibility that these may not be constant across time and space has been advanced (Hermalin, 1966). In particular, conclusions from the published PHE models relate to estimates based on short 5-year windows concentrated in periods around the end of the 20th century so may not be typical of longer periods. However, long-term analyses are lacking to date. In part, this may be because the estimate of the rate of population ageing in a given year depends on the lifetime experiences of all cohorts alive at the time and therefore detailed information for a century or so earlier is required and there are few such cases available. We therefore present analyses for century-level timescales

Comparison of methods

22. The population projections method is based on changes in the rates between the base and final years of the analysis period; in the case of a 5-year interval, only differences in that interval contribute to differences at the

end of a period such as 2005-2010. In contrast, the PHE methods depends on the lifetime experiences and numbers in the birth cohort that contribute to the population at a given time point. Figure 2 shows which cohorts and the parts of the Lexis surface contribute to estimates of changes in mean age between the start years of 1900 (blue hatched) and 2005 (shaded area) and the final year of 2010 (red hatched). In the 1900 and 2010 case, the data values used are non-overlapping, whereas in the 2005 and 2010 case, differences in cohort sizes and rates up to about 100 years earlier are used, even though the interval is only five years, which is typical of the intervals using this approach.

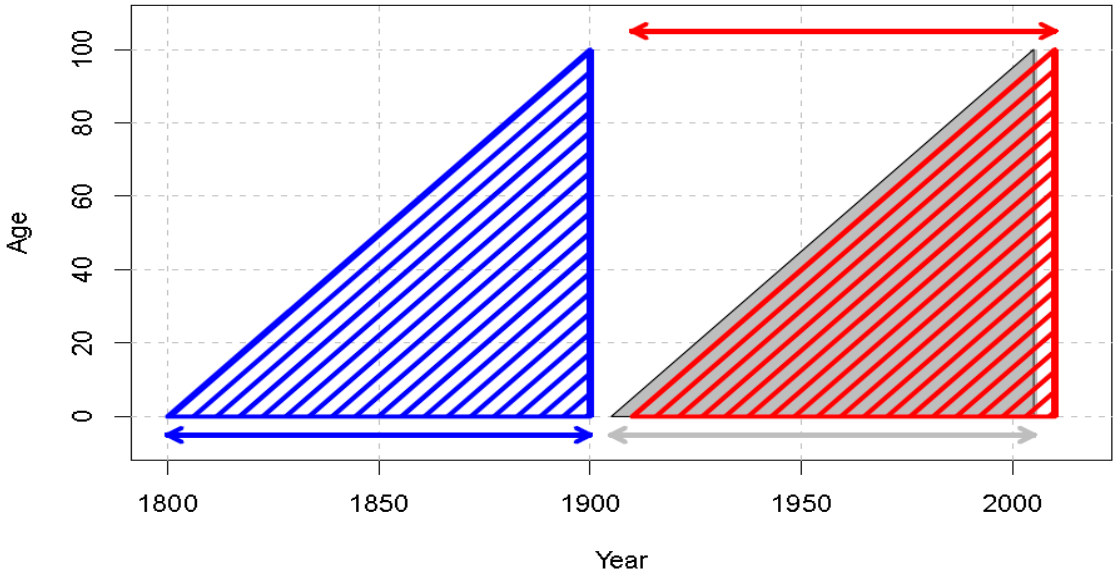

Figure 2. Data used for PHE estimation in years 1900, 2005 & 2010

23. The PHE method requires no assumptions (except some relating to technical decisions about how to implement a formal model based on continuous function when data are available only in discrete form, but these are substantively unimportant). Results do not depend on decisions about the period over which analysis is undertaken (again, there may be decisions about how the 100-year rule for prior data requirements may be relaxed as done by Preston and Stokes (2012) who devote considerable attention to this issue since they used UN data only available from 1950). The PHE method is transitive, i.e. the value comparing *T1* and *T*2 is simply the value between times *T1* and *T*3 plus the value between *T3* and *T2*, where *T3* is an intermediate time.

24. For the population projections method, the role of a component such as fertility on population ageing between *T1* and *T2* is conventionally estimated by assuming fertility is constant from the first time point and the impact is measured by the difference in projected and actual values at time *T2*, rather than allocating the actual difference between values at *T*1 and *T*2 to fertility, mortality and migration.

25. The assumption of constancy in one variable is a strong one when the other components are assumed to retain their actual values. In practice, components do not move independently, except possibly in the short-term, most obviously in the case of the assumption that fertility and mortality are independently distributed when much attention is given to how they interact. While long-term projections with constant values can be produced, it is likely that the actual population will be compared with one either tending to zero or infinity. The United Nations Population Division (2000) analysis of the role of migration as a response to population ageing emphasises that apparently reasonable steps taken sequentially can lead to nonsensical outcomes. In addition, the method in not transitive (although it is possible to add this requirement, more sophisticated models are required).

26. The PHE approach compares the population structures of the same population at different points of time, whereas the projections approach compares two populations at the same time but which have been subject to different demographic rates over a well-defined period. In contrast, even for changes over a single year, the PHE method requires mortality and migration rates for the relevant cohorts in Figure 2 back to their time of birth, so includes rates for a century earlier for centenarians, but only uses rates for the previous year for infants.

27. The PHE method decomposes changes in ageing between birth cohort size and lifetime cohort mortality and net migration; it does not include fertility explicitly. The direct effect of mortality improvement at any age among the older cohorts will lead to population ageing *ceteris paribus*. However, lives 'saved' at young ages may lead to subsequent additional births and this indirect effect may act to offset population ageing. This point had been emphasised by Horiuchi (1991, p. 42): "It is important to distinguish direct and indirect effects of mortality changes on population growth. The present method [using age-specific growth rates $r(a,t)$] is concerned with direct mortality effects only. Mortality reduction, however, has some indirect effects. … Such indirect mortality effects working through fertility are difficult to assess when the present method is adopted". He concluded that the population projections method includes both direct and indirect effects." Recently, Lee and Zhou (2013) have again drawn attention to these apparent differences in attribution of the demographic determinants of population ageing. They pointed out that the PHE approach does not allow for the role of changing fertility. They used a comparative population projections approach for India over the period 2005-10, the period chosen for direct comparison with the findings of Preston and Stokes (2012). They showed that with this model, fertility decline was the main factor in population ageing. This was consistent with the formerly-accepted conventional explanation as summarised by Wilmoth (2015a) and in contrast to the "revisionist" conclusion of others such as Caselli and Vallin (1990).

Comparison of results with alternative models

28. The data for the PHE model are used are taken from the Human Mortality Database (HMD) that includes estimates of mortality rates and population size by single year of age and sex for each calendar year together with information on total annual numbers of births and deaths. These estimates are constructed using a uniform method applied to information from validated official statistics such as censuses, vital registration and population estimates. Further details about the database and the construction of these data are available (Wilmoth, et al., 2007; Human Mortality Database, 2015). Since we are interested in long-term trends, we confine attention to Sweden, which has by far the longest run of high quality data over period 1751-2013 and England & Wales over 1841-2013, but which can be extended to 2113 with similar detailed national official projections data (Office for National Statistics, 2015).

29. Figure 3 shows changes in population mean ages by decade (labelled Total) and the components of Birth Cohort, Mortality and Net Migration under the PHE model. Changes were small until about 1850, but increases in the next 100 years were driven largely by birth cohort effects (including the indirect effects of mortality and migration). However from the middle of the 20th century, direct mortality effects dominate, with birth cohort effects becoming negligible (since annual births were relatively constant). These findings ae consistent with Hermalin's (1966) predictions. Migration has a relatively small contribution to either population ageing or the reverse over the period although it could act to accelerate population ageing in the 21st century if net migration fails to continue the increasing trend of recent periods.

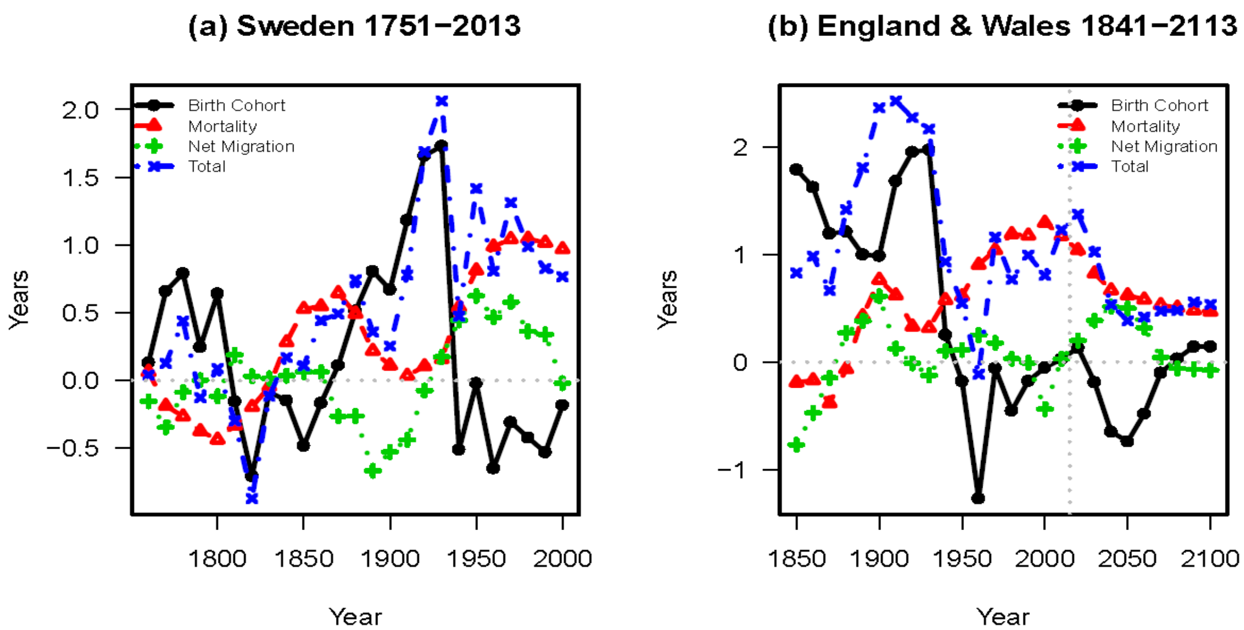

Figure 3. Change in Mean Age over Subsequent Decade

30. Table 2 shows the results of a projections exercise with initial year 1970 using United Nations 2015 data in the Spectrum package. Because England and Wales data are not available, United Kingdom data have been used instead. Some simplifications were required, since, for example, data are only available in 5-year bands. For comparability with PHE method, mean ages are shown. Over the period, mean age increased by an average of about one year per decade. In Sweden, the three components of fertility, mortality and migration had similar effects as measured by the difference between actual and scenario values in 2015 (although in opposite directions). A similar pattern is observed for the UK, although fertility change has a much stronger effect. However, this does highlight problems of interpretation of such results. First, the migration assumption is of no migration rather than constant migration. With base year in the current period, this would lead to very substantial differences in years to come. The other is that the fertility effect reflects the differential impact of the initial fertility value and those experienced in the intervening period. In both countries, the average TFR over the period was 1.8, but the initial value in 1970 was 2.0 in Sweden and 2.2 in UK. Therefore the difference in the role of fertility is due to the fact that the difference is much greater in the UK than in Sweden. Therefore the results are sensitive both to the assumptions made and to periods included. Around this time, UK TFR varied from 2.9 in 1964 to 1.7 in 1977, which would lead to very large difference in the role of fertility on ageing.

	Projection Year		Difference	
	1970	2015	2015 - 1970	2015 Scenario - Actual
Sweden				
Actual	37.1	41.7	4.6	-
Fertility fixed	37.1	40.1	2.9	1.6
Mortality fixed	37.1	40.0	2.8	1.7
Migration zero	37.1	43.3	6.2	-1.6
UK				
Actual	35.9	40.5	4.6	-
Fertility fixed	35.9	37.5	1.5	3.0
Mortality fixed	35.9	39.5	3.6	1.0
Migration zero	35.9	41.9	6.0	-1.4

Table 2. Mean ages and differences under alternative scenarios, Sweden and United Kingdom

IV. Summary and conclusion

31. Some of the principal differences in these alternative approaches for assessing the impact of fertility and mortality are summarised in Table 3.

Property	Projections	PHE	Stable population
Method	Population projections	Formal model	Formal model
Outcome	Compare change in ageing indicator at same time point under alternative scenarios	Decomposition of change in mean age into cohort survival and migration, and birth cohort numbers	Implied population distribution
Assumptions	Substantial	None	Choice of values to present
Comparison period	Demographic rates in period *T1* to analysis year *T2*	Cohort survival and migration rates, and number of births in century before initial time period *T1* and final time period *T2*	Tabular comparison
Transitive	Not in usual form	Yes	No
Data requirements	Standard population projections	Substantial - for 100 years before initial estimate	Readily available
Comprehensiveness	Shows overall impact of differential rates	Provides only direct impact of mortality and migration; fertility included as component of birth cohort term	Does not relate to actual populations

Table 3. Main differences between Projections, PHE and Stable population models

32. While the question of the relative contribution of fertility and mortality to population ageing is one that has been discussed for many decades, there does not appear to be a clear unique answer to the question. All methods are correct, but they emphasise different aspects. The question of what is the appropriate test for determining whether fertility or mortality is more important for population ageing, and what conditions are responsible for the results remains open.

Acknowledgements

Thanks are due to the University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany) for access to the Human Mortality Database (http://www.mortality.org/cgi-bin/hmd/DataAvailability.php), and to the statistical offices in England & Wales and Scotland for provision of original data (http://www.mortality.org/hmd/GBR_SCO/DOCS/ref.pdf).

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