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A New Perspective on Population Aging

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Abstract

In Sanderson and Scherbov (2005) we introduced a new forward-looking definition of age called "prospective age" and argued that its use, along with the traditional backward-looking concept of age, provides a more informative basis upon which to discuss population aging. Age is a measure of how many years a person has already lived. Everyone of the same age has lived the same number of years. In contrast, prospective age is concerned about the future. Everyone with the same prospective age has the same expected remaining years of life.

In this paper, we first explore the concept of prospective age in detail and show, using an analytic formulation, historical data, and forecasts, that prospective age is, in most cases, insensitive to whether it is measured using period or cohort life tables. We, then, use the two age concepts in concert and demonstrate how this enriches our understanding of population aging in developed countries since 1960.

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A New Perspective on Population Aging

Warren C. Sanderson and Sergei Scherbov

1. Introduction

The literature on population aging in developed countries is exploding. Serious concerns have been expressed about the challenges to current economic and social arrangements associated with an ever more elderly population.[1] In contrast to the growth of interest in population aging, the concepts used in analyzing it have remained static. In Sanderson and Scherbov (2005) we presented a new forward-looking definition of age called "prospective age".[2] This paper explores the nature of this new age measure and shows how it can be used to enrich our understanding of population aging.

In our new approach, people have two different ages. Chronological age, or as we call it, "retrospective age", is a measure of how many years a person has already lived. Everyone of the same age has lived the same number of years. In contrast, prospective age is concerned about the future. Everyone with the same prospective age has the same expected remaining years of life. The two measures of age are complementary. One is forward-looking while the other is backward-looking. They quantify two different aspects of aging. It is only by combining a forward-looking measure of age with the usual backward-looking one that we can see the complete picture. Discussing population aging only in terms of retrospective age can be misleading and result in poorly-designed policies.

The most commonly used measure of population aging is the change in the median age of the population. If, for example, the median age of a population were to rise from 40 to 45 over the half century from 2000 to 2050, we are lead implicitly to think that the average person in the population of 2050 would behave like a 45 year old in 2000, but because of life expectancy increases this is unlikely to be the case. A 45 year old in 2050 might well behave in many ways like a 35 year old in 2000, because the 45 year old could have the same remaining life expectancy as a 35 year old person in 2000. It is precisely because many behaviors depend on the number of years left to live that it is important to supplement the usual backward-looking definition of age with a forward-looking one.

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[1] See, for example, Commission of the European Communities (2005); Ezrati (1997); Kotlikoff and Burns (2004).

[2] In Sanderson and Scherbov (2005) we used the terminology "age" and "standardized age" to refer to the concepts of "retrospective age" and "prospective age" respectively.

Strategies of saving and investment are clearly forward-looking behaviors. Understanding them requires that we know not only how old people are, but how many years they expect to live as well. The acquisition of education is another. For instance, retired people are more likely to take courses to help them enjoy new leisure time activities if they have more expected years of life. Requests for and the provision of certain medical procedures also depend on the number of remaining years of life. One example of this is knee replacement surgery, which is now often performed on people above the age of seventy. It would not make much sense to do this if the operation did not significantly increase a person's number of years of mobility.

It is important to have a forward-looking measure of age not only because many behaviors are influenced by a person's expected remaining years of life, but because important economic and social magnitudes depend on it as well. For example, medical expenditures are especially high in the last years of life. In forecasting these expenditures, it is important to take into consideration that, with increasing life expectancies those last years of life happen at an ever older age.[3] Forecasting medical expenditures only on the basis of (retrospective) age produces figures that are too high and could lead to erroneous policy decisions. The same is true with respect to forecasts for specific health-related items, such as the need for nursing home beds. Thus, supplementing the concept of age with the concept prospective age allows us to analyze aging more deeply than if we were to use only one age measure.

The aging of populations and of people have different dynamics. Surviving people must grow one year older each year. Populations, on the other hand, do not necessarily grow one year older each year. Populations can grow more than one year older, less than one year older or even grow younger with the passage of time. When age is measured as a two dimensional variable our descriptions of population aging grow more complex. With two median ages to consider, populations can simultaneously grow younger according to one measure and older according to the other. This bivariate approach allows us to describe the history of population aging and its likely future more comprehensively.

Demographers have not previously had a forward-looking measure of age, so in Section 2, we describe the new concept of prospective age. The fundamental feature of prospective age is that it is a time-horizon consistent measure, because all people with the same prospective age have the same expected number of years ahead of them, regardless of the number of years that they have already lived.

The expected number of years of remaining life that people have at a particular age is their cohort life expectancy, so it is natural to use that life expectancy concept in computing prospective age. Period life tables, on the other hand, are much more widely available than cohort ones. Unfortunately, the levels of period age-specific mortality rates are influenced by the rate of change of those rates making them less easily interpretable.[4]

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[3] See, for example, Miller (2001); Yang et al. (2003); Seshamani and Gray (2004); Stearns and Norton (2004); Zweifel et al. (2004).

[4] See Bongaarts and Feeney (2002, 2003); Horiuchi (2005).

If period and cohort prospective ages produced different pictures of population aging, the usefulness of the concept of prospective age would be limited. On the other hand, if the implications for understanding population aging were fundamentally the same regardless of whether period or cohort life tables were utilized, we could apply the concept of prospective age to the entire range of countries that had a suitable time series of period life tables.

So, in Section 3, using formulas in Goldstein and Wachter (2005) based on a special case of a Gompertz model of adult mortality, we derive analytic results for the relationship between period and cohort prospective ages. We show there that, in this special case, period and cohort prospective ages are almost identical.

In Section 4, we present a historical perspective on population aging using both median ages and prospective median ages. We present calculations for Sweden from 1800 to 1945 and for England and Wales from 1868 to 1941. The terminal dates of the periods were determined by availability of the most up-to-date cohort life table when the data were downloaded. Two conclusions clearly emerge. First, adding prospective median age to the (retrospective) median age in analyzing aging histories does indeed produce interesting new observations. Both countries, for example, experienced periods when they were growing older as indicated by increasing median ages and when they were growing younger as indicated by their decreasing prospective median ages. They also experienced intervals when they were growing older according to both median age measures. Second, prospective median ages are again remarkably similar regardless of whether they are computed using period or cohort life tables.

In Section 5 we turn from looking at the aging histories of Sweden and England and Wales to peering into the future of aging in the United States through 2050. We do this by assuming two different patterns of mortality change: (1) the slowing of life expectancy gains assumed by the United Nations, and (2) the continuation of current speed of life expectancy increase observed in low mortality countries. Despite a significant increase the median age of Americans, their prospective median age changes very modestly if at all. As in the previous two sections, we find only minor differences between prospective median ages depending on whether cohort or period life tables are used in their computation.

In Section 6 we present the recent histories of population aging in 20 countries for which information is available in the Human Mortality Database using the median age and the prospective median age computed using period life tables. By means of three comparative histories of population aging, Denmark/Norway, Belgium/Netherlands, and Austria/Hungary, we show that the consideration of population aging in two dimensions sharpens our understanding. Section 7 contains some concluding thoughts.

2. Prospective Age

Imagine two people, one alive in 1950 and the other in 2000. If these two people both were 40 years old (or alternatively had a retrospective age of 40), then naturally each would have lived 40 years by those two dates. People who share a prospective age, on the other hand, share a remaining life expectancy. If a 40 year old person in 1950 had a remaining life expectancy of 30 years, and a 50 year old person in 2000 also had a remaining life expectancy of 30 years, then the 50 year old in 2000 would have a prospective age of 40, using 1950 as a year of reference. In this case, all people who had a remaining life expectancy of 30 years would have a prospective age of 40 (again using 1950 as the reference year).

Retrospective age does not need any reference year to be understood. For example, all people who have a retrospective age of 40 were born 40 years earlier. Prospective age, in contrast, requires a year of reference, called the "standard year". All people who have a prospective age of 40 have the same remaining life expectancy as a 40-year old person in the standard year.

The computation of a retrospective age also requires us to specify our year of interest. For example, if we wanted to determine the prospective age of a 50 year old person in 2000, then the year 2000 is our year of interest. We call this year the "index year". We have to specify the index year in determining a person's prospective age because, even holding the standard year fixed, people of the same (retrospective) age in different years will generally have different prospective ages.

Figure 1 shows diagrammatically how prospective age is defined. The left-most pair of figures shows two columns of a life table for a person of age *a* in the index year. The first column contains the person's age and the second, the life expectancy at that age. The right-most pair also shows two columns of a life table, but they are written as the mirror-image of the first two. The last column contains an age of a person in the standard year, and the next-to-the-last column contains the life expectancy of people of that age. The prospective age of a person of age *a* in the index year is the age in the standard year, denoted by *A* in the Figure, such that the remaining life expectancy of a person of age *a* in the index year is the same as the remaining life expectancy of a person of age *A* in the standard year.

Retrospective Age	Remaining Life Expectancy		Remaining Life Expectancy	Prospective Age
a	$\mathrm{RLE}_a^{\mathrm{index}}$	=	$\mathrm{RLE}_A^{\mathrm{standard}}$	A
Life Table of Index Year			Life Table of Standard Year	

Figure 1. Diagram showing how prospective age is determined.

For example, let us choose 2000 as the index year and 1950 as the standard year. Suppose a 50 year old person in the index year, 2000, had a remaining life expectancy of 30. In Figure 1, *a* would be 50 and the remaining life expectancy in the second column would be 30. Next suppose that a 40 year old person in the standard year, 1950, would also have a remaining life expectancy of 30 years. In this case, *A*, would be 40 and the figure in the third column of the table would be 30.

3. The Relationship Period and Cohort Prospective Ages in Theory

Remaining life expectancies and therefore prospective ages can be calculated using period life and cohort life tables. Besides generating different values of prospective ages, the choice of life tables corresponds to a choice between two polar types of expectation formation. The use of period life tables corresponds to the assumption that people have myopic expectations, ones in which they believe that future mortality rates will be the same as they are in the current situation. The use of cohort life tables corresponds to the assumption that people have perfect foresight about future changes in those rates. Neither is plausible. People do look ahead in forming their expectations, but they cannot predict the future exactly.

Large differences between period prospective age and cohort prospective age would pose a problem, because we would need to know how people formed expectations about their longevity in order to determine which prospective age to use. On the other hand, if the differences between prospective ages based on myopic expectations and perfect foresight were inconsequential, then we would not need to know exactly how expectations were formed because most reasonable mechanisms of expectation formation would produce results somewhere between the two extremes.

If period and cohort prospective ages were very different from one another, then we would always have to face the question of which one is better to use. If they were close enough so that we would make the same inferences about population aging using either one, then data availability would drive the decision about which one to use.

It is helpful to begin our study of the difference between period and cohort prospective ages with some mathematical notation. Let $e_p(a,t)$ be life expectancy at age a in year t calculated using period life tables and $e_c(a,t)$ be the life expectancy of people of age a in year t computed using cohort life tables. Both refer to people born in the year t-a, but in the first case remaining life expectancy is computed using the mortality rates in period t while in the second we use the cohort mortality rates after year t of the people born in year t-a.

Using this notation, the period prospective age of a person of (retrospective) age a in index year I (using the standard of year S), which we denote by A_p, can be computed from Eq. (1),

$$e_p\left(A_p,S\right)=e_p\left(a,I\right), \tag{1}$$

and the cohort prospective age of a person of (retrospective) age a in index year I (using the standard of year S), A_c, can be computed from Eq. (2).

$$e_c\left(A_c,S\right)=e_c\left(a,I\right). \tag{2}$$

Eq. (1) suggests the following procedure. Look up the life expectancy of people of age a in year I using a period life table. This is the number on the right-hand side of Eq. (1). Next, go to the period life table for year S. The age in that life table that produces the same life expectancy we just found for people of age a in year I is A_p, the period prospective age. The cohort prospective age is found using the same process, except that cohort life tables are used instead of period ones.

Goldstein and Wachter (2005) present formulas for the remaining life expectancies at adult ages computed using period and cohort life tables. These formulas allow us to write down simple equations that relate retrospective and prospective ages when the two types of life tables are used.[5] The assumptions underlying the Goldstein-Wachter results are simplifications that are sometimes closer and sometimes farther from observed patterns of mortality rates. Nevertheless, even though they are derived only for a particular model of adult mortality, the equations for period and cohort prospective ages provide us with insight into their relationship that cannot be gained in any other way.

An example of what we can learn from the equations can be seen in Eq. (3) and Eq. (4), which we have computed using Eq. (A3) and Eq. (A7) in the Appendix, and data for Swedish females, setting (retrospective) age, a, equal to 27, the index year, I, equal to 1830, and the standard year, S, equal to 1930.[6]

$$A_p = 27 + 0.111 \cdot (S - I), \tag{3}$$

and

$$A_c = 27 + 0.118 \cdot (S - I). \tag{4}$$

Both equations have two additive terms on the right-hand side. The first terms are always equal to (retrospective) age a (in this case, 27). The only difference between period and cohort prospective ages arises because of the differences in the coefficients of $(S\text{-}I)$ in the second terms. We show in the Appendix that these differences are always small, and therefore, period and cohort prospective ages are always reasonably close to one another.

In this example, where 100 years separate the standard and the index years, the empirical period prospective age of 27 year old Swedish women in 1830 is 38.1 (using 1930 as the standard year) and her empirical cohort prospective age is 39.0, 0.9 years higher. The formulas in Goldstein and Wachter imply that the cohort perspective age would be 0.7 years higher. This is quite a close approximation to what we observe.

Perhaps an analogy can sharpen our intuition about prospective age. Imagine that we had a paragraph written in English and that we first translated it into German and then back into English. Next, we took the same paragraph and translated it into French and then again back into English. This is similar to what we do when we compute prospective age. When we calculate it on the basis of period life tables, we translate (retrospective) age, a, into remaining life expectancy in year I. Then we translate that remaining life expectancy back into the prospective age using the period life table for year S. This translation forward and then backward, is like translating the paragraph from English to German and then back again. In this example, doing the same thing using French is the parallel of doing the computation with cohort life tables.

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[5] The derivation of the relationships between retrospective and prospective ages based on the equations in Goldstein and Wachter (2005) appears in the Appendix.

[6] The data are from the Human Mortality Database downloaded on March 1, 2005.

The English text when translated into German looks very different from the text in French, just like remaining life expectancy is very different depending on whether it is measured using period or cohort life tables. But when both the German and French texts are translated back into English, we get a much more similar result than we had before the reverse translation. The same is true with respect to period and cohort prospective ages. Both involve a forward translation from age to life expectancy and then a backward translation from life expectancy to age. The forward and the backward translations are made using consistent types of life tables. Although the results of the first translation from age to life expectancy are different depending on whether period or cohort life tables are used, those differences are largely undone when the same sort of life tables are used in reverse.

4. Historical Examples of Population Aging from Sweden and England and Wales

The most common measure of population aging is the increase in the median (retrospective) age of its members (Gaurilov and Heuveline 2003). We have been arguing in this paper that demographers need to think about age as a two dimensional concept, incorporating both retrospective and prospective ages. It follows from this that we also need to think about population aging in two dimensions, using both the retrospective median age and the prospective median age of the population.

The median age of a population is the age that divides the population into two numerically equal groups. The prospective median age is defined as the prospective age of a person at that median age. For example, if the median age of a population in 1950 was 30 and the prospective age of a 30 year old in that year was 35 (using the year 2000 as a standard), then the population's prospective median age in 1950 would be 35 (given the standard year of 2000). With two clarifying assumptions, everyone in a population can be assigned a prospective age.[7] In this case, the prospective median age is identical to the median of the population members' prospective ages.

In Figure 2, we graph the median age of the Swedish population from 1800 to 1944. This is supplemented with the prospective median age calculated using period and cohort life tables. The median age of the Swedish population was 26.2 in 1800. It remained roughly constant for two decades and then declined to 24.1 in 1838. Subsequently, it increased slowly, reaching 26.3 in 1900 and 27.7 in 1920. After 1920 the median age began to rise rapidly, hitting 33.0 in 1940.

[7] The median age is the median of people's retrospective ages. Therefore, the terms "retrospective median age" and "median retrospective age" refer to the same concept and can be used interchangeably. The situation with respect to prospective ages is a bit more complex. When the index year is later than the standard year, remaining life expectancies at young ages may be so high that there is no age in the standard year with a corresponding life expectancy. In these cases, we assign a prospective age equal to the age in the standard year that has the highest remaining life expectancy. Once this is done, every person in the index year has a corresponding prospective age and we can appropriately speak of a median prospective age. In this case, the median value of all the prospective ages is identical to the prospective age of people in the population who are at the median retrospective age. This allows us to use the terms "prospective median age" and "median prospective age" interchangeably.

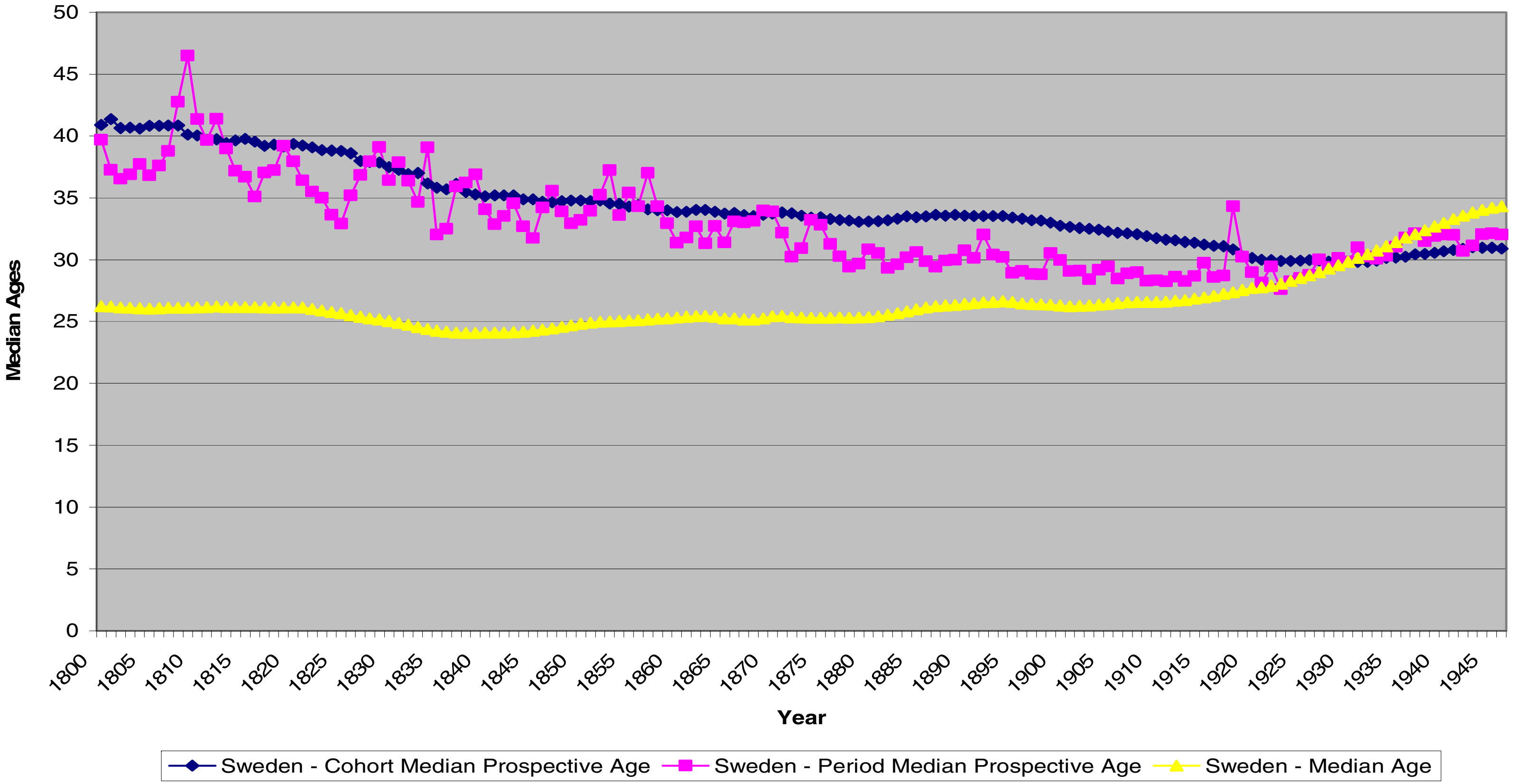

Figure 2. Sweden: Median age and prospective median ages computed with period and cohort life tables, 1800-1944.

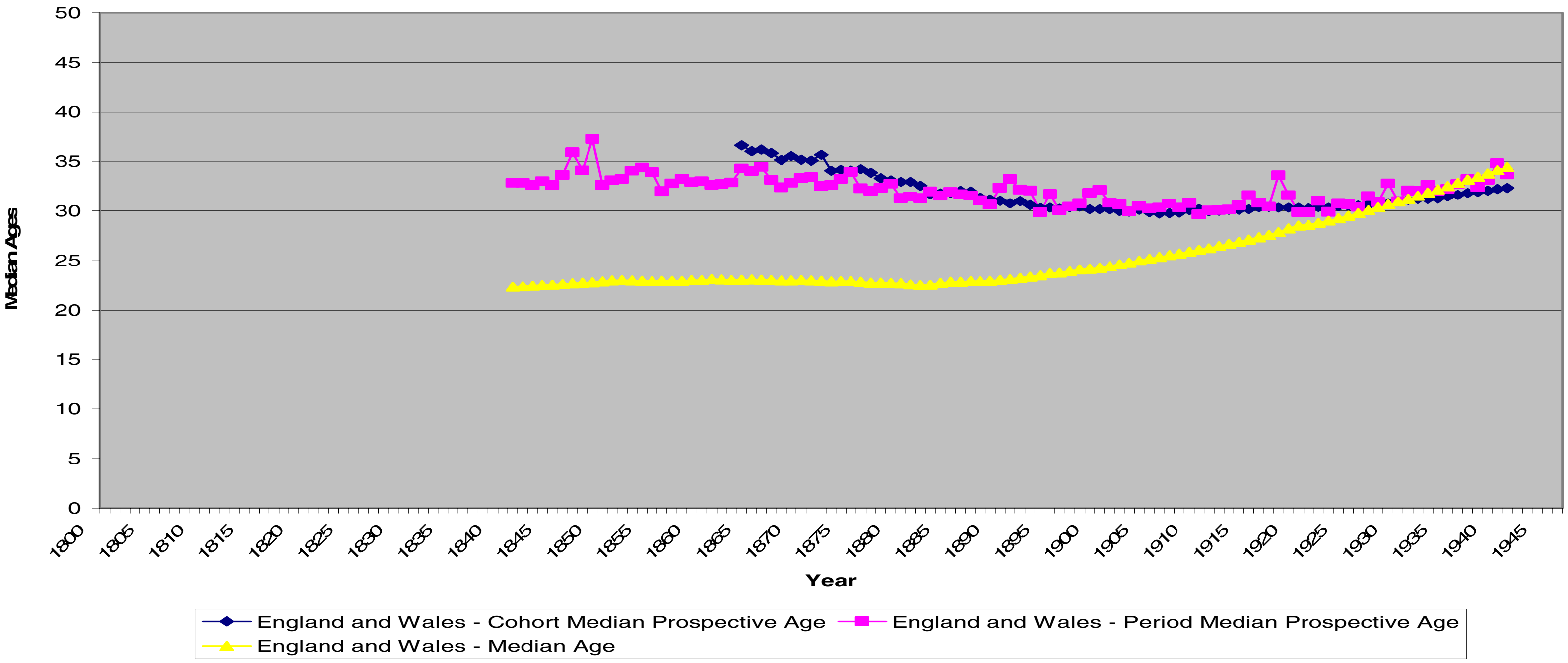

Figure 3. England and Wales: Median age and prospective median ages computed with period and cohort life tables, 1869-1941.

From the vantage of the prospective median age, the history looks quite different. Using 1930 as the standard year, the prospective age was around 40 in 1800 and fell, sometimes more rapidly, sometimes more slowly, until the mid-1920s when it began a slow rise. Over the period 1800 to 1946, the median (retrospective) age of the Swedish population increased by around 8 years. Over the same period, the prospective median age decreased by around 9 years.

Figure 3 is similar to Figure 2 except that it deals with England and Wales. For ease of comparison, we have drawn the two graphs on the same time scale, even though the series for England and Wales are shorter. In 1841, the median age in England and Wales was 22.4, 1.7 years younger than in Sweden. In the subsequent one hundred years, aging was more rapid in England and Wales. The median age there increased by 12.1 years, but only by 8.6 years in Sweden. As with Sweden, most of the increase in the median age happened after the mid-1880s. The prospective ages both fall from 1864 through the first decade of the 20th century and then begin to increase slowly.

In Figures 2 and 3, we see an upward spike in the period prospective ages in 1918, the year of the Spanish flu epidemic. Remaining life expectancy at the median ages in 1918 were low relative to nearby earlier and later years. These unusually low life expectancies correspond to unusually high ages in the standard year, 1930.

While the Spanish flu epidemic affected period prospective ages in 1918, it influenced cohort prospective ages over an entire generation. People born in 1848, for example, experienced strong increases in their morality rates in 1918, when they were 70 years old. Cohort life tables for all groups affected by the epidemic show lower remaining life expectancies in the years prior to 1918 than they would have shown in the absence of the epidemic. When the standard year is after 1918, as it is in the two figures, the lower remaining life expectancies are reflected in cohort prospective ages that are higher than they would have been had there been no epidemic.

Like Sweden, England and Wales also experienced a prolonged period of rising median retrospective ages and falling prospective ages. Although there are some differences, one clear conclusion from Figures 2 and 3 is that, in the long-run, prospective ages using period and cohort life tables follow nearly the same paths. The inferences that we would make regarding the historical patterns of aging are largely independent of which type of prospective age measure we use.

5. Population Aging in the Future

In the past, mortality changes did not correspond to the simple Gompertz model discussed in Section 3, but nonetheless prospective ages computed using period and cohort life tables were quite similar. In this section, we briefly look into the future in order to see whether the kinds of mortality changes that we forecast are also likely to produce prospective median ages that are insensitive to whether cohort or period life tables are used. Here we use the United States as our example. Our procedure is (1) to forecast mortality rates,[8] (2) to create period and cohort life tables, and (3) to compute prospective median ages using both sorts of tables. Two different life expectancy forecasts are used, the United Nations forecasts and one based on the assumption that life expectancy at birth would increase by 0.2 years per calendar year. The latter is about the average increase experienced in high life expectancy countries since 1960.[9]

Figure 4 shows the evolution of the median age of the US population and prospective median ages using the UN assumptions about the course of future mortality rates. In this example, the median age rises from 36.3 years in 2000 to 42.7 years in 2050. The rise in median age is initially more rapid and, after the mid-2030s, much slower. As expected, prospective ages show a slower increase. When measured using period life tables, the prospective median age rises from 36.3 years in 2000[10] to 38.5 years in 2025 and then falls to 38.3 years in 2050. Using cohort life tables, it increases from 36.3 years in 2000 to 38.3 in 2025 and then decreases to 38.9 in 2050. The difference in the two prospective ages in 2050 is only 0.6 years. Further, both series reach a peak in 2036. Clearly, in this example, perspective age and the kinds of inferences that we might make from its path are not sensitive to whether period or cohort life tables are used.

Figure 5 is the analogous figure using instead the assumption that US life expectancy at birth will increase by 0.2 years with the passage of each calendar year. This is a faster pace of improvement than assumed by the UN and it results in a higher US median age in 2050, 2.4 years more than when the UN life expectancies were used. Using period and cohort life tables, the prospective age is roughly constant from 2000 to the late 2030s after which it falls. The prospective median age in the US in 2050 computed on the basis of period life tables is 35.9 years, while measured using cohort life tables it is 1.2 years lower. In this example as well, it is evident that the story of aging that we obtain using the median age and the prospective median age derived either from period or cohort life tables is essentially identical.

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8 Mortality rates forecasts were made using a Brass relational model. We fit the UN life expectancy at birth forecasts and the ones based on the assumption of a constant annual increase by changing one parameter, the intercept. For the standard we used the most recent age-specific mortality schedule.

9 Oeppen and Vaupel (2002) found that female best practice life expectancy increased consistently by an average of 0.25 years per calendar year over the last one and a half centuries. Sanderson and Scherbov (2004) showed that the average life expectancy increase in a group of low mortality countries from around 1960 to around 2000 was about 0.20 years per calendar year. The assumption of a 0.20 year increase, on average, in life expectancy at birth was used in creating mean forecasted mortality paths in the probabilistic population forecasts in Lutz et al. (2001, 2004) and Sanderson and Scherbov (2005).

10 The year 2000 is used as the standard in these examples.

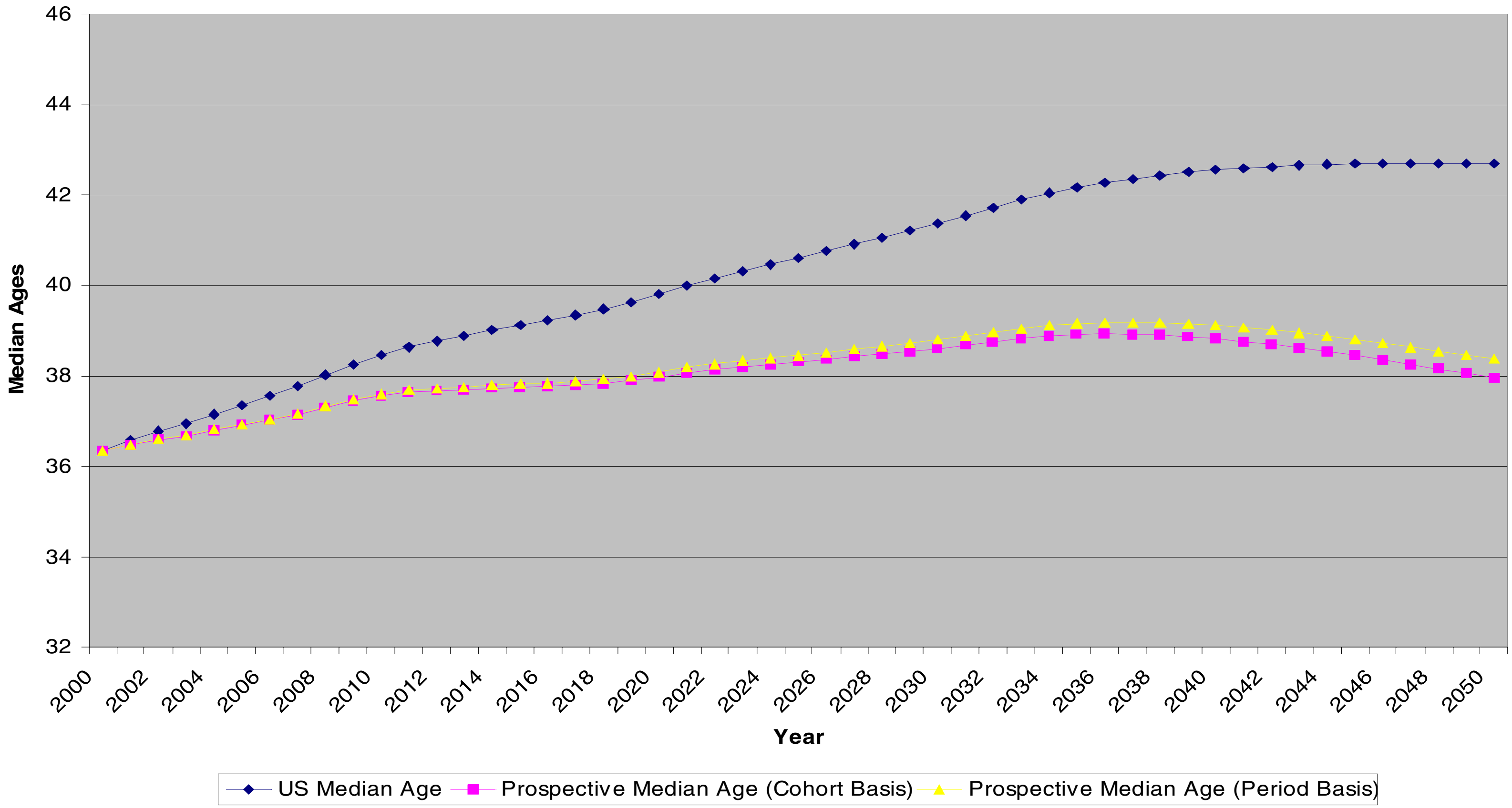

Figure 4. US: Median age and prospective age computed with period and cohort life tables, 2000-2050, based on the United Nations life expectancy assumptions.

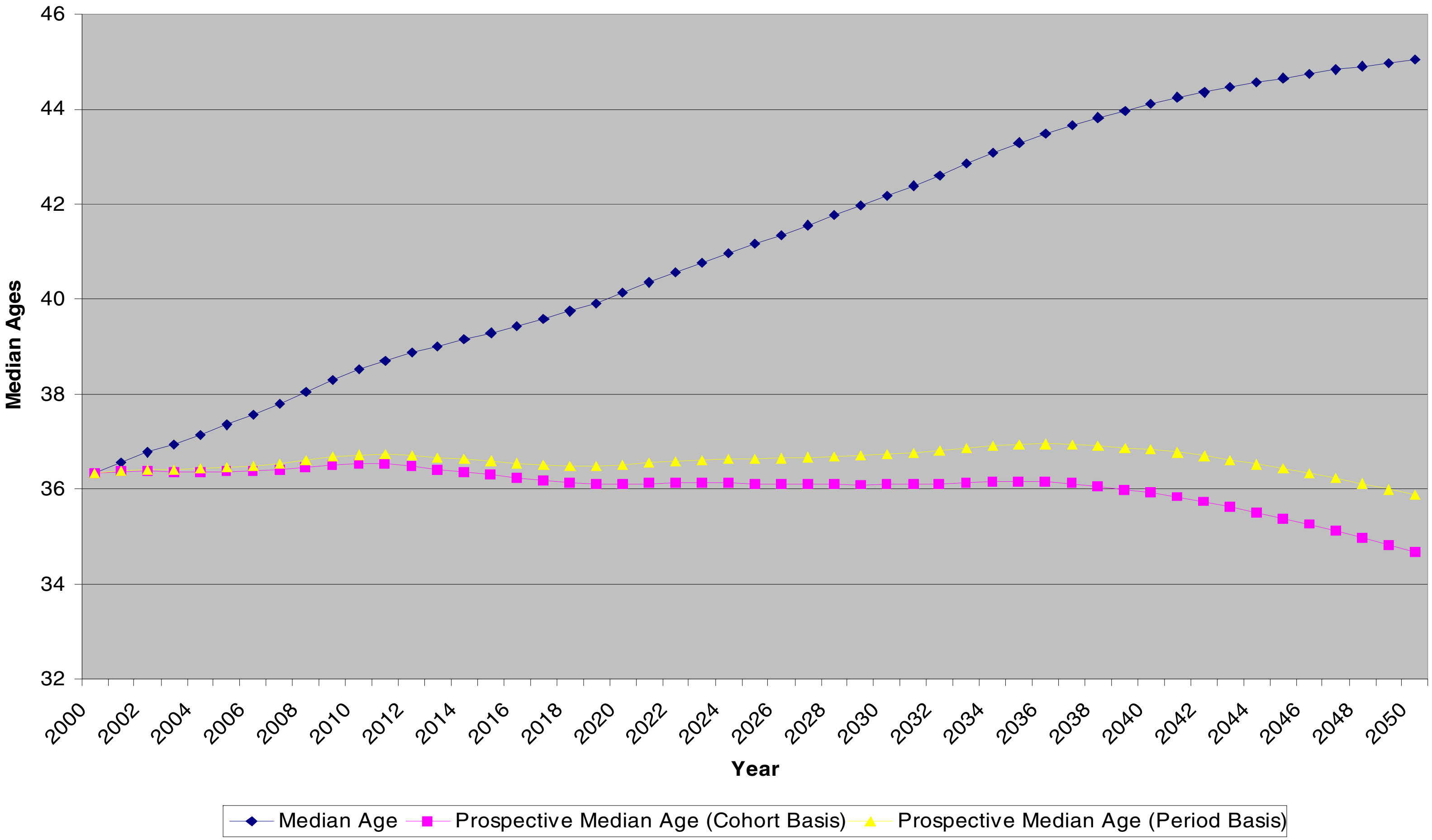

Figure 5. US: Median age and prospective age computed with period and cohort life tables, 2000-2050, based on the assumption that life expectancy at birth increases by 0.2 years per calendar year.

These examples are not a test of whether future prospective ages will be the same, regardless of whether they are measured on a cohort or period basis. We cannot possibly know this. But this is not the question that we are addressing here. The thesis of this paper is that we can understand population aging better if we use both the median age and the prospective median age together. With respect to the prospective age, it does not matter much whether we use the variant based on cohort life tables or the one based on period life tables. We get the same results either way. We have now adduced three quite different types of evidence for this: (1) a theoretical model, (2) historical observations, and (3) two forecasts. They all consistently show only relatively small differences between prospective ages based on period and cohort life tables. This allows us to move on to the next section, where we investigate recent patterns of aging using both the median age and the prospective median age based just on period life tables.

6. The Recent History of Aging in Developed Countries

Table 1 contains median ages and prospective median ages for the female populations of all the countries in the Human Mortality Database for 1950, 1975, and 2000,[11] using period life tables. As we showed above, prospective ages computed using period and cohort life tables tend to be quite similar and give the same broad inferences with respect to population aging. In any event, it is impossible to produce the numbers in Table 1 using cohort life tables, because the required tables do not exist yet. The table is produced using the life table for England and Wales in 1980 as a standard. By using a particular country's life table as a standard, prospective ages are commensurate across countries. In other words, every person with a prospective age of 35 has the same remaining life expectancy as a 35 year old in England and Wales in 1980.

Because of increasing life expectancies, prospective median ages rise less rapidly than median ages. Japanese females had the fastest increase in their median age, going from 23.1 years in 1950 to 42.6 years in 1999. The increase in prospective median age was much smaller, rising from 32.7 years in 1950 to 35.9 years in 1999. But Japan did not have the fastest increase in its prospective median age. That distinction goes to Bulgaria. The Bulgarian female population was also young in 1950, with a median age of 27.3 years. Its prospective median age, at that time, was 31.6 years, 1.1 years below Japan's. Over the subsequent five decades, Bulgaria's prospective median age rose to 42.7 years, 6.8 years higher than Japan.

Canada and the US are the youngest countries in Table 1. The Canadian data end in 1996. In that year the median age of Canadian women was 35.8, 0.2 years higher than in the US. On the other hand, its prospective age in that year was 31.9, 1.4 years lower. In 2000, France, Norway, and Spain had prospective median ages that were lower than in the US.[12] Switzerland and the Netherlands had prospective median ages that were less than one year higher.

[11] Exceptions to the indicated years are marked in Table 1.

[12] Canada was probably lower as well.

Table 1. Median age and period prospective median age for 20 countries in the Human Mortality Database, 1950, 1975, and 2000.

Country	1950		1975		2000	
	Median age	Prospective median age	Median age	Prospective median age	Median age	Prospective median age
Austria	37.0	41.6	36.2	37.5	39.1[b]	35.5[b]
Belgium	36.5	40.8	36.1	37.3	40.0	36.3
Bulgaria	27.3	31.6	34.3	36.7	41.2	42.7
Canada	27.5	31.0	27.7	26.8	35.8[d]	31.9[d]
Denmark	32.3	36.0	34.0	33.9	39.4	37.7
England & Wales	36.4	39.9	36.2	36.3	38.3[c]	35.6[c]
Finland	29.5	35.1	32.8	33.5	40.8	37.1
France	36.6	40.3	33.6	33.1	38.9	33.4
FRG	35.9[a]	39.4[a]	37.5	38.9	40.9[b]	37.4[b]
GDR	40.1[a]	42.9[a]	38.1	40.5	42.4[b]	39.4[b]
Hungary	31.2	36.8	36.2	39.0	40.5[b]	42.4[b]
Italy	29.4	33.3	35.0	35.2	41.6	36.5
Japan	23.1	32.7	31.3	31.2	42.6[b]	35.9[b]
Netherlands	28.7	31.4	30.2	29.3	38.2	34.8
Norway	33.3	35.1	33.6	32.4	37.8	33.9
Russia	-	-	35.3	37.5	38.8[b]	41.9[b]
Spain	28.6	33.4	31.6	31.5	38.6	33.2
Sweden	34.8	38.1	36.6	35.6	40.7	36.2
Switzerland	34.4	38.1	34.0	32.7	39.6	34.3
USA	-	-	29.7	29.5	36.5[b]	34.0[b]

[a] 1956

[b] 1999

[c] 1998

[d] 1996

There are many comparisons that can be made using the data on median ages and prospective median ages underlying Table 1. Here we will just focus on three historical examples: (1) Denmark and Norway, (2) Belgium and the Netherlands, and (3) Austria and Hungary.

Figure 6 shows the median ages for Denmark and Norway. In 1950, Denmark and Norway had similar median ages and prospective median ages. Danish women had a slightly lower median age, 32.3, compared to 33.4 for Norwegian women. In terms of prospective median ages, Danish women were slightly older, with a prospective median age of 36.0, 0.9 years older than their Norwegian counterparts. Since 1950, the broad movements in median ages and prospective median ages were also similar with an upward movement from 1950 to the mid-1960s, a downward movement for around the next ten years, followed by a period of renewed rise. The most striking difference is the gap that emerged between the prospective median age of Danish and Norwegian women. In 2002, the prospective median age of Norwegian women was 3.7 years younger than that for Danish women.[13]

A second interesting feature of Figure 6 is the relationship between median age and prospective median age during the 1990s. In both countries, median ages rose at a rate of around one year per decade. Prospective median ages, on the other hand, hardly budged. During this period, increases in the median age and increases in adult life expectancies had almost equal and opposite effects on prospective ages.

While the recent story of population aging in Denmark and Norway is one of divergence, the comparison between Belgium and the Netherlands in Figure 7 provides an example of convergence. In 1950, the population of the Netherlands was considerably younger than the population of Belgium. The median age of Dutch women was 28.7 in that year, 7.8 years younger than the median-aged Belgian women. By 2002, that gap was reduced to 1.9 years. In 1950, the prospective median age of Dutch women was 31.4 years, 9.4 years younger than that in Belgium. By 2002, the difference was only 1.5 years. The prospective median age fell during the period in Belgium and rose in the Netherlands.

Another interesting aspect of Figure 7 is the rapid increase in both the median age and the prospective median age of Dutch women since 1980. Such a rapid rise in both median ages is seen only in the figures for the Netherlands.

The recent aging histories of Austria and Hungary are interesting not only because they were two of the pillars of the pre-World War I Austro-Hungarian Empire, but also because of their different experiences since the end of the Second World War. In 1950, Austria was a comparative old country, with a median age for females of 37.0. In contrast, Hungary was a relatively young country with a median age of 31.2. As can be seen in Figure 8, between 1950 and 1999, both countries aged. The median age rose slightly in Austria, to 39.1 in 1999 and quite rapidly in Hungary, passing Austria and reaching 40.5 in 1999.

[13] This difference is mainly due to a comparatively slow increase in Danish life expectancies.

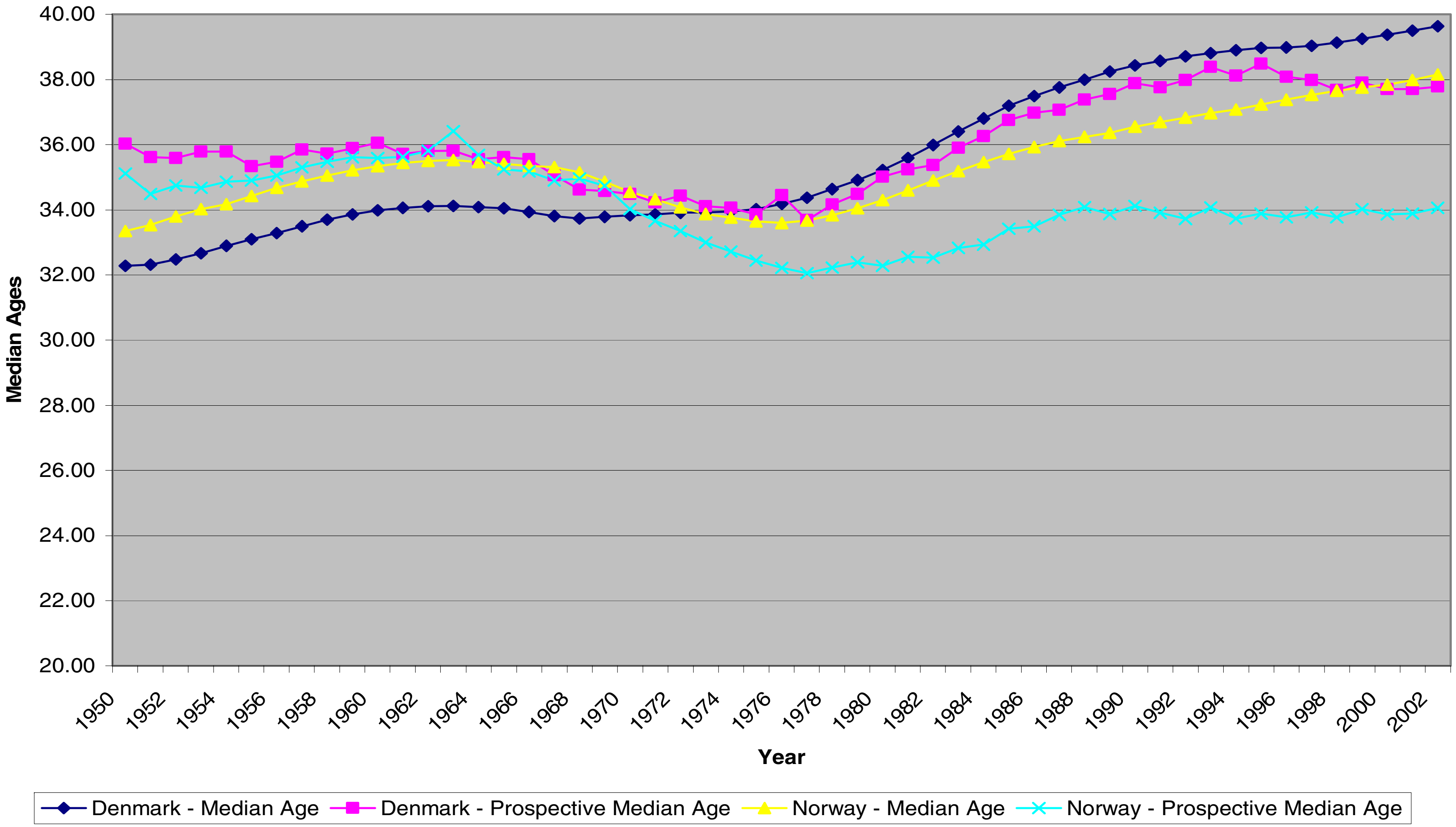

Figure 6. Denmark and Norway: Median age and prospective median age (period basis), 1950-2002.

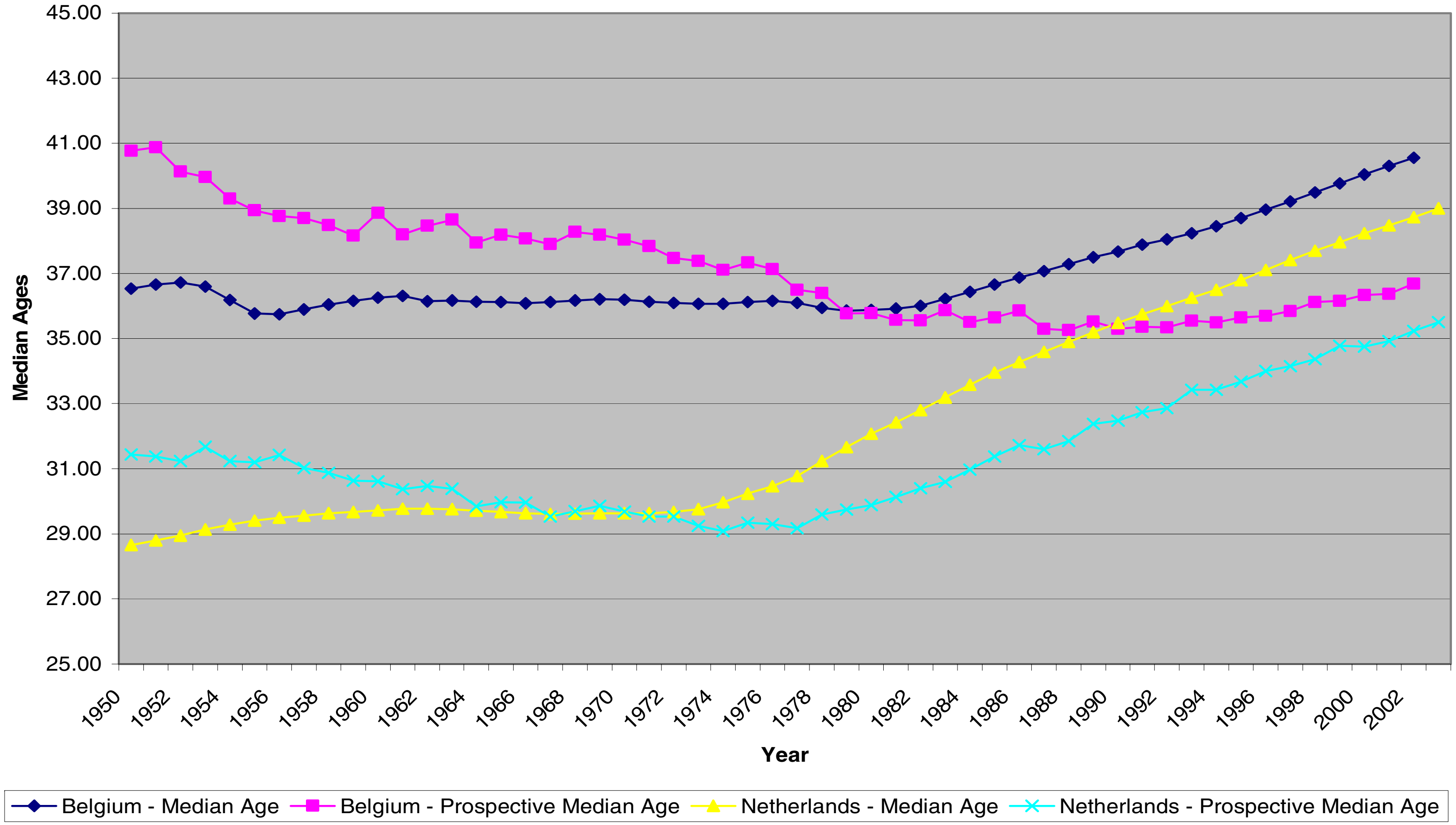

Figure 7. Belgium and the Netherlands: Median age and prospective median age (period basis), 1950-2002.

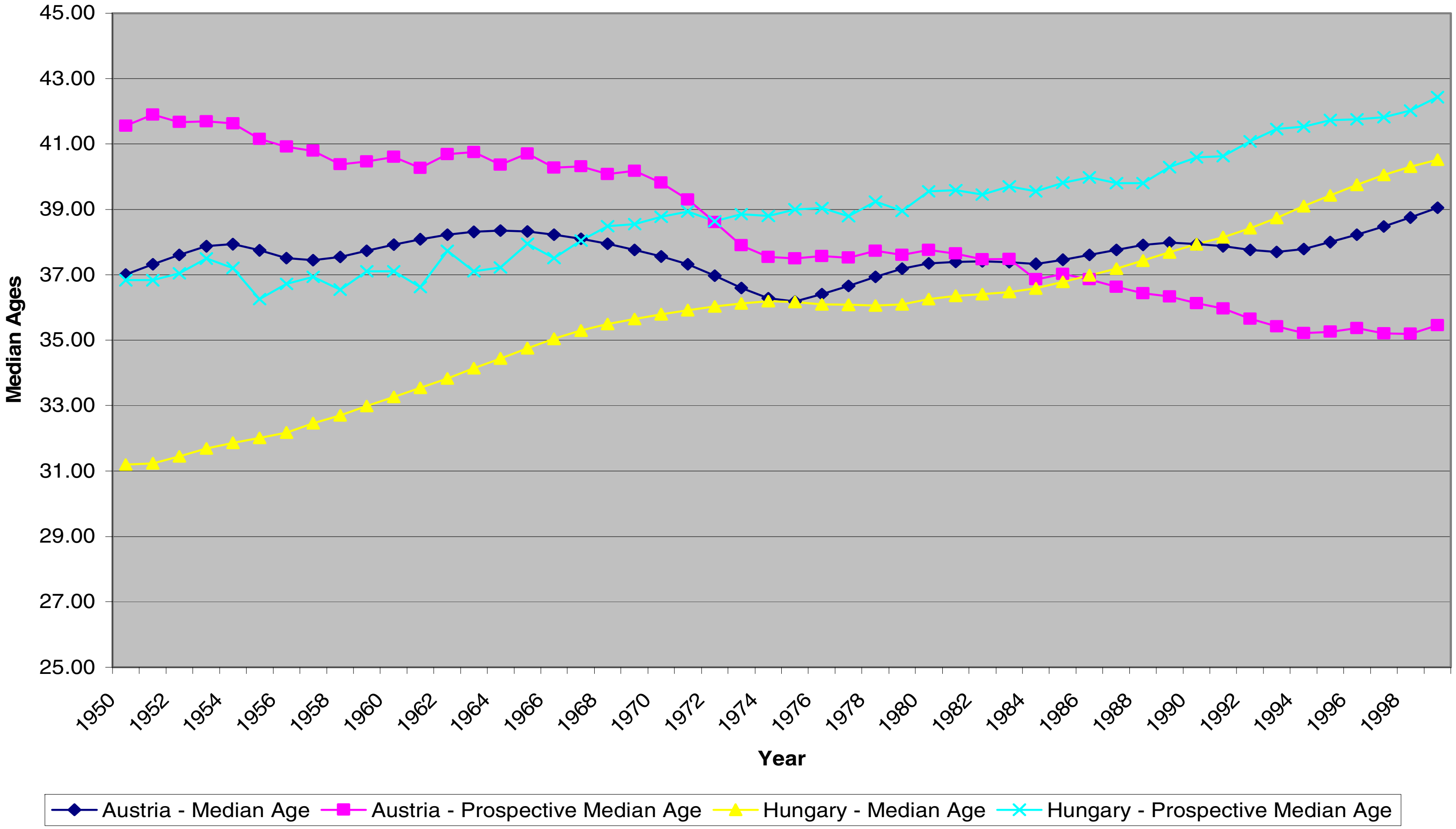

Figure 8. Austria and Hungary: Median age and prospective median age (period basis), 1950-2002.

From the vantage of prospective age, however, the history is enriched with another story. Austria, the relatively old country in 1950, experienced a half a century in which its prospective median age fell. By 1999, it was 6.1 years lower than it was in 1950. During the same period, the prospective median age in Hungary increased by 5.6 years. In 1999, Austria had a prospective median age close to Hungary's in 1950 and Hungary had a prospective median age close to Austria's in 1950. According to its prospective median age, Austria can no longer be considered a country with a particularly old population. More countries in Table 1 have prospective ages above Austria's than have lower ones. Hungary clearly has a relatively old population. In 1999, its prospective median age was the highest of any country in the table.

The comparisons that we have emphasized here are examples of how our reading of the history of population aging is enriched when both forward- and backward-looking measures are taken into account.

7. Conclusions

The traditional measure of population aging, the change in the median age, provides a highly incomplete picture of aging and can result in poorly designed policies. The median age is a backward-looking measure of age. We have proposed that median age be supplemented with a forward-looking measure of age, prospective age, and that population aging be considered simultaneously in both its backward-looking and forward-looking aspects.

The computation of prospective age requires life tables. In order to demonstrate that prospective age is useful as well as analytically interesting, we needed to show that the conclusions that we would reach with regard to aging were not sensitive to whether period or cohort life tables were used in its calculation. We demonstrated this analytically in Section 3, with historical data for Sweden and England and Wales in Section 4, and with population forecasts in Section 5. This allowed us to present the recent history of population aging in 20 countries enriched by using both the median age and prospective median age (derived using period life tables).

There are a number of different ways of supplementing the (retrospective) age with a forward-looking counterpart. In Sanderson and Scherbov (2005), we considered two of them, prospective age and the expected number of years of remaining life. Using prospective age has three advantages. First, because it is an age measure, prospective age and (retrospective) age are commensurate. This allows us to analyze changes in median age and changes in prospective median age in an exactly parallel fashion. It is easy enough to tell the histories of population aging in terms of median ages and median remaining life expectancies. In our judgment, comparing ages is more natural, but people with different tastes could well prefer the combining ages with remaining lifetimes.

The second advantage of using prospective age is that it has an explicit comparative reference. For example, someone of prospective age 30 in the index year has exactly the same remaining life expectancy as someone of age 30 in the standard year. If we were to use a recent year as the standard, prospective age translates age into a magnitude for which we have an intuitive feel. When we use remaining life expectancy, this immediate comparison is lacking. Finally, and most importantly, prospective age is quite insensitive to whether it is measured using period or cohort life tables. This is not the case when we consider remaining life expectancies.

One difference between the two foreword-looking age concepts is that the measurement of remaining life expectancies does not require a standard year, while the measurement of prospective age does. It is always possible to study aging using both concepts, as we did in Sanderson and Scherbov (2005), but the robustness of prospective age to how it is measured makes it particularly attractive, especially in situations where cohort life tables are absent.

Research using a forward-looking measure of aging is just beginning. We believe that the approach will be useful in sociology and economics, where it can be used to study the timing of life cycle events, such as retirement. Because prospective age is a time-horizon consistent age, it can be readily integrated into economic models. Changes in median prospective ages might also be helpful in forecasting changes in savings and investment behavior, the school attendance of older people, and the cost of health care.

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Appendix

Goldstein and Wachter (2005) investigate the case where adult mortality hazard rates take on the Gompertz form $h(a,t) = \alpha \cdot e^{-kt} \cdot e^{\beta \cdot a}$, where $h(a,t)$ is the hazard rate at age a in year t, and α, β, and k are parameters (see Eq. (17) in Goldstein and Wachter (2005)). Given those adult hazard rates Goldstein and Wachter (2005) (in their Eq. (21)) show that period life expectancy at an adult age, for example age a, can be written:

$$e_p(a,I) = r \cdot (I - b) + k_b(a), \tag{A1}$$

where $e_p(a,I)$ is life expectancy at age a in index year I, r is the annual rate of increase of life expectancy at age a and $k_b(a)$ is life expectancy at age a in the base year b. Given the Gompertz hazard rates, r is a constant and is equal to $\frac{k}{\beta}$.

Life expectancy at the period prospective age A_p in the standard year S can be written as:

$$e_p(A_p,S) = r \cdot (S - b) + \Delta_{S,p} \cdot (A_p - a) + k_b(a), \tag{A2}$$

where $\Delta_{S,p} = \frac{e_p(A_p,S) - e_p(a,S)}{A_p - a}$. Note that $\Delta_{S,p}$ is a negative number.

Period prospective age is computed from the equation $e_p(A_p,S) = e_p(a,I)$. Solving this equation for A_p yields:

$$A_p = a + \left(\frac{r}{-\Delta_{S,p}}\right) \cdot (S - I). \tag{A3}$$

Using the Goldstein and Wachter equation for the cohort life expectancy of an adult of age a in year I (see their Eq. (23)), we can write:

$$e_c(a,I) = \left(\frac{r}{1-r}\right) \cdot (I - b) + f(r,a,b), \tag{A4}$$

where b is the base year, $f(r,a,b)$ is a function of r, a, and b, but is constant over time. People who are a years old in year I were born in year I-a. People at the cohort prospective age of A_c in the standard year S, were born in year S-A_c. So first we write down the expression for the cohort life expectancy of people of age a who were born in the year S-A_c using Eq. (A4). Those people are of age a in year S-A_c+a.

$$e_c(a, S - A_c + a) = \left(\frac{r}{1-r}\right) \cdot (S - A_c + a - b) + f(r,a,b). \tag{A5}$$

The cohort life expectancy of people of age A_c in the standard year S can now be expressed as:

$$e_c(A_c,S) = \left(\frac{r}{1-r}\right) \cdot (S - A_c + a - b) + \Delta_{S,c} \cdot (A_c - a) + f(r,a,b), \tag{A6}$$

where $\Delta_{S,c} = \dfrac{e_c(A_c, S) - e_c(a, S - A_c + a)}{A_c - a}$.

Solving the equation $e_c(A_c, S) = e_c(a, I)$ for A_c, we get:

$$A_c = a + \left(\frac{r}{-\Delta_{S,c} \cdot (1-r) + r} \right) \cdot (S - I). \tag{A7}$$

The only difference between the equations for period prospective age (A3) and cohort prospective age (A7) is in the coefficients of the *S-I* term and this difference is almost always quite small. This can be seen from Table A1, where we have computed the coefficients of the *S-I* terms for various possible prospective ages for the standard years 1840 and 1940, and for values of *r* equal to 0.1 and 0.25.

Table A1. Coefficients of *(S-I)* terms in Eq. (A3) and Eq. (A7) for various possible prospective ages and for two values of *r*.

Possible Values of Prospective Age (*a=25)*	*S=1940*				*S=1840*			
	r=0.1		*r=0.25*		*r=0.1*		*r=0.25*	
	Period[a]	Cohort[b]	Period[a]	Cohort[b]	Period[a]	Cohort[b]	Period[a]	Cohort[b]
30	0.111	0.115	0.277	0.280	0.133	0.134	0.332	0.316
35	0.111	0.117	0.277	0.285	0.135	0.138	0.338	0.324
40	0.111	0.118	0.278	0.286	0.137	0.139	0.344	0.326
45	0.112	0.119	0.279	0.288	0.140	0.139	0.349	0.326

Notes: The coefficients were derived from data for Swedish females taken from the Human Mortality Database.

[a] Coefficient of *(S-I)* in equation (A3).

[b] Coefficient of *(S-I)* in equation (A7).