The Characteristics Approach to the Measurement of Population Aging

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MOST STUDIES OF population aging focus on only one characteristic of people: their chronological age. This is the case, for instance, in the UN's reference volume, *World Population Ageing, 1950–2050* (United Nations 2001). The implicit assumption is that other characteristics relevant to population aging do not change over time and place. But clearly, they do. To take an obvious example, 65-year-olds today generally have higher remaining life expectancies and are healthier than their counterparts in earlier generations—reflected, in many countries, in rising ages of eligibility for public pensions (McLaughlin, Jette, and Connell 2012; Christensen et al. 2009; OECD 2012). Many important characteristics of people vary with age, but age-specific characteristics also vary over time and differ from place to place. Focusing on a single aspect of the changes entailed in population aging but not on all the others provides a limited picture of the process, one that is often not appropriate for either scientific study or policy analysis.

A small part of the large and growing literature on population aging has taken a broader view of the process, considering characteristics of people beyond their chronological age: remaining life expectancy, health and morbidity, disability rates, and cognitive functioning. It begins with Ryder (1975). Ryder wrote (p. 16):

> To the extent that our concern with age is what it signifies about the degree of deterioration and dependence, it would seem sensible to consider the measurement of age not in terms of years elapsed since birth but rather in terms of the number of years remaining until death.…

> We propose that some arbitrary length of time, such as 10 years, be selected and that we determine at what age the expectation of life is 10 years, that age to be considered the point of entry into old age.…

Ryder used this definition of the threshold of old age to tabulate those entry ages for the Coale–Demeny "West" family of model life tables (Coale and Demeny 1966). In addition, he computed the proportions old, under his definition, for a variety of model stable populations.

The importance of Ryder's reasoning was realized only slowly. Ryder himself made no further use of it, and the next paper that applied it came almost a decade later. Two reasons might explain the delay. First, Ryder's discussion appeared in an article about stable populations, not about aging. Aging was not a topic of much interest to the demographic community at the time, when the major policy concern was rapid population growth in less developed countries. When concern about population aging began to increase, Ryder's research on stable populations was not an obvious reference. Second, Ryder's interest seemed limited to defining a more meaningful threshold of old age. For many demographers this was not a pressing issue. The convention that people became elderly at age 65 seemed both simple and sensible. In essence, Ryder was providing an answer to a question that almost no one was asking.

Siegel and Davidson (1984b) were the first to apply Ryder's proposal to actual data. They used two durations of remaining life expectancy, 10 and 15 years, to define ages at which old age began for the United States in census years from 1920 to 1980. Like Ryder, they computed proportions of the population that were "old" according to those definitions. (Interestingly, the proportion old was the same in 1980 as it was in 1940.) Siegel and Davidson also realized that remaining life expectancy as a characteristic could be used for more than defining the old-age threshold. They suggested that it could also be used in the design of government programs, such as, in the United States, in indexing the age for receiving a full Social Security pension.

When we wrote Sanderson and Scherbov (2005), we were unaware of this previous literature. In that article, we pointed out that age could be computed both backwards, as the number of previous birthdays, and forwards, based on remaining life expectancy. We used our forward-looking age to compute what we subsequently called prospective age, which is chronological age adjusted for changes in life expectancies. We used this to introduce a new indicator of aging, the *prospective median age*. We also presented a new version of the conventional old-age dependency ratio, where the threshold ages at the beginning and the end of the working-age period were adjusted for changes in life expectancies. Determining the prospective median age is different in an important way from the calculations of Ryder and Siegel and Davidson. In both of those earlier studies, the level of a characteristic was chosen and this determined a series of ages associated with that level. For the prospective median age, there is no fixed level of a characteristic that can be used.

Ideas similar to ours were independently arrived at by Shoven (2007). The intellectual ancestor of Shoven (2007)—and the related articles, Shoven (2008) and Shoven and Goda (2010)—was not the demographer Norman Ryder but the economist Victor Fuchs. Fuchs (1984) was interested in the proportion of the population that was elderly. He tabulated data for the US using three different definitions: (1) the proportion of the population 65+, (2) the proportion of the population 65+ who would die in the succeeding five years, and (3) the proportion of the population 65+ who are not in the labor force. Definitions (2) and (3) supplement chronological age with characteristics of people that change over time.

The Siegel and Davidson estimates of proportions elderly in the United States have been updated (Siegel 1993, 2011). Other than in these publications, Ryder's ideas about age and aging remained unused until Heigl (2002) proposed an interesting application. Heigl wanted to obtain a quantitative measure of the changes over time in the active life expectancy of the elderly. To do this, he used Ryder's threshold age for becoming elderly and computed active life expectancy from that age forward. Heigl was the first to propose a measure that combined two time-varying age-specific characteristics. However, according to the *Web of Science* (Thompson Reuters), Heigl's article, which was written in German, has up to now never been cited.

Although there have been further developments (Lutz, Sanderson, and Scherbov 2008; Sanderson and Scherbov 2007, 2010), the methodology still lacks a name, a formal set of equations and definitions, and awareness that the literature taken together can be seen as forming a new paradigm in conceptualizing population aging. We call it the *characteristics approach*. With the growing interest in aging populations and in policies toward them, we believe this approach may prove to be especially useful.

Characteristic-based measures of age

Let $C_t(\alpha)$ be a schedule of some characteristic relevant to the study of population aging (such as remaining life expectancy), giving the values of the characteristic at each chronological age α. The schedule is allowed to vary over time. If $C_t(\alpha)$ is continuous and monotonic in α, it can be inverted to obtain the schedule of chronological ages associated with each particular value of the characteristic at time t. We call these α-ages.

Most directly, α-ages can be calculated from the inverse of the characteristics schedule. Thus the chronological age $\alpha_{\kappa,t}$ at which the level of a specified characteristic is κ at time t would be given by

$$\alpha_{\kappa,t} = C_t^{-1}(\kappa_t), \tag{1}$$

where C_t^{-1} is the inverse of the characteristic schedule at time t. In the simplest case the level of the characteristic does not change over time, so that κ has no t subscript. For example, if the time-invariant characteristic was a remaining life expectancy of 15 years, the α-age—the age at which that remaining life expectancy was attained—for Americans (average of both sexes) in 2010 is found to be 71 years and 1 month. We call the α-ages based on invariant characteristics *constant characteristic ages*.

The characteristics approach to the measurement of population aging includes the conventional measure of chronological age but is far more general. For concreteness, we focus on four characteristics: (1) chronological age, (2) remaining life expectancy, (3) the mortality rate, and (4) the proportion of adult person-years lived after a particular age. (The same approach allows the use of many other characteristics as well.) Each of these characteristics has a particular interpretation for the study of population aging. Chronological age is included both to show how conventional measures can be naturally embedded in the generalized framework and to provide a quantitative benchmark against which to assess the importance of including other characteristics. Remaining life expectancy is included because it can be used to produce a forward-looking definition of age. The mortality rate is included because it can be used as a rough but easily measurable ordinal indicator of the health of a group of older people. Finally, we include the proportion of adult person-years lived after a given age because it can be used to construct a simple hypothetical demographically indexed public pension system.

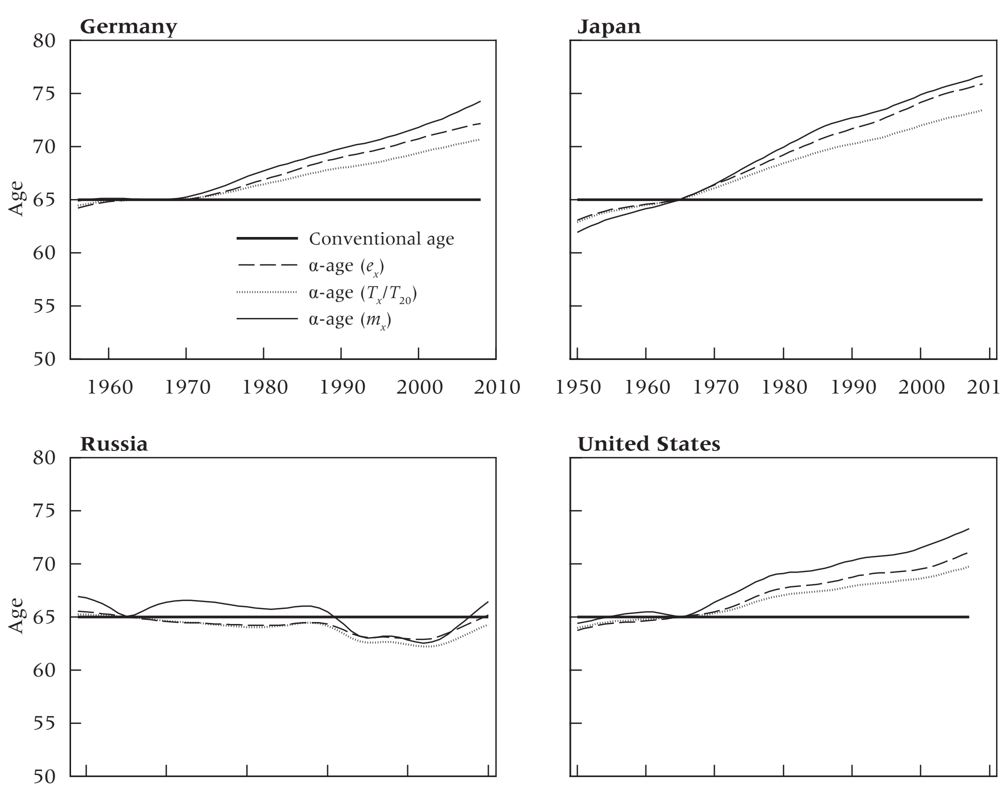
We use those four characteristics to provide a perspective on an age-old question: how old do you need to be to be considered "old"? In this case, the α-age at which people make the transition into the category "old" generally varies over time. We call the resulting trajectories "transition trajectories"—one for each of the four characteristics. Ryder (1975) and Siegel and Davidson (1984a) computed transition trajectories on the basis of remaining life expectancy.

A health-based characteristic could also be used to mark the entrance to old age. Health is a complex quality, but a rough and readily accessible measure of it would be to associate population health at each given age with the level of the corresponding age-specific mortality rate. In this case, α-ages based on the life-table mortality rate m_x would provide ages of comparable population health across space and time (Cutler et al. 2007; Vaupel 2010; Fuchs 1984) and could also be used to mark the transition to old age.

Another important transition is the one at which people become eligible for a full public pension. Pension systems become unsustainable if eligibility ages are fixed while life expectancy steadily rises. α-ages allow us to specify a simple alternative public pension system where the fraction of adult person-years spent eligible for a pension remains constant. Such a system is equitable in the sense that the ratio of years of pension to years in the working ages remains fixed, even as life expectancy changes. We call the ratio of person-years lived at age x and beyond to the number of person-years lived from age 20, T_x/T_{20} in life-table notation, the "life-course ratio" because it allows fruitful links to life-course studies (Lee and Goldstein 2003). In the special case where the life-course ratio is equal to the proportion of adult person-years in which people are eligible for a pension in a specific base year, the corresponding α-age provides an easily understood measure that defines the age at pension eligibility and can therefore be used to inform discussions of pension age changes.

In Figure 1, we show the α-age transition trajectories for the onset of old age in four countries that have experienced significant aging—West Germany, Japan, Russia, and the United States—using the four illustrative characteristics. To facilitate comparison, we set the values of the characteristics at the levels observed for 65-year-olds in each country in 1965. The standardization

FIGURE 1 α-ages associated with three population aging characteristics—remaining life expectancy (e_x), the mortality rate (m_x), and the life-course ratio (T_x/T_{20})—for West Germany, Japan, Russia, and the United States, c. 1950–c. 2010



NOTE: Spline smoothing, keeping the α-ages for 1965 equal to 65.
SOURCE: Human Mortality Database (accessed February 1, 2012) and authors' calculations.

highlights the comparative trends in the transition trajectories across the four countries.

In each country panel in Figure 1 we show the three α-age transition trajectories and a horizontal line for age 65. By construction, all four lines coincide at age 65 in 1965. The α-age e_x transition trajectory shows the chronological ages that had the same remaining life expectancies as observed in the country at age 65 in 1965. The α-age m_x transition trajectory shows the chronological ages at which people had the same single-year mortality rate as was observed in the country at age 65 in 1965. The α-age T_x/T_{20} transition trajectory does the same thing for the life-course ratio.

Two features of the chart are evident. First, Russia has had a pattern of aging distinctly different from those of the other three countries. Instead of having rising ages at the transition to old age after 1970, it has fluctuating α-ages with no clear trend. With little improvement in survivorship at older ages, the onset of old age did not change much. Russia's experience is similar to that of many other Eastern European countries. Second, since 1970 in the other three countries, the m_x-based α-age rises faster than the ages for the other two characteristics, and the α-age based on the life-course ratio rises the most slowly. For example, keeping the α-age constant in the United States would have meant that the age at eligibility for a full public pension would have risen at a rate of about 1.3 months per year over the period 1965–2010. A constant α-age pension reform in the US that began in 1965 would have brought the pensionable age to 69.8 by 2007. In comparison, using the m_x-based α-age, we can see from the chart that people 73.4 years old in 2007 would be as healthy as 65-year-olds in 1965. Therefore, people who retired at age 70 in 2007 would be healthier than people who retired at age 65 in 1965. A similar pattern can be seen for West Germany and Japan, indicating that initial retirees under our simple pension rule would have become, on average, healthier over time.[1]

Characteristics-based measures of population aging

In the conventional framework, age itself is not an object of study. If people have always grown old at age 65 and if they will always grow old at age 65 in the future, there is nothing to study. The age at the onset of old age is fixed forever. However, if our interest is in the capabilities, functioning, and health of people, then changing characteristic schedules become of substantive interest. Conventional measures of population aging have the form

$$MC_t = f(S(a,t), H(a)), \tag{2}$$

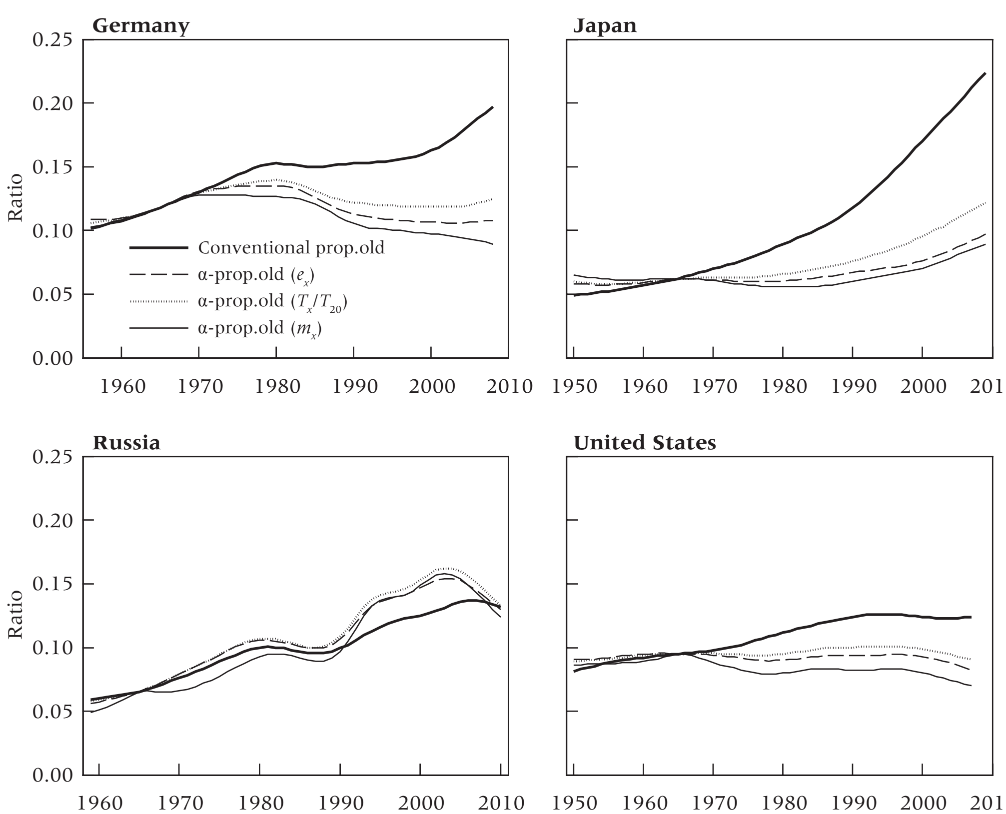
where MC_t is the conventional measure of aging at time t, $S(a,t)$ is the age structure of the population at time t, and H is a matrix of age-specific characteristics. $S(a,t)$ can be a vector of the number of people by age or a matrix of the number of people by age, sex, and other informative dimensions. The key feature of conventional measures is that H is independent of time. Age structures of populations are allowed to change over time, but the characteristics of people are not. The new characteristics-based measures have the form

$$MN_t = g(S(a,t), H(a,t)), \quad (3)$$

where MN_t is the new measure and the matrix $H(a,t)$ now includes time-varying age-specific characteristics.

We discuss three families of measures. To identify them, we introduce the terms elder proportions, elder ratios, and elder relationships. *Elder proportions* have the form $\Sigma_a s_{a,t} h_{a,t} / \Sigma_a s_{a,t}$ where $s_{a,t}$ is the population at age a and time t, $h_{a,t}$ are the age-specific characteristics, and the summation is over all

FIGURE 2 Elder proportions (proportions old) computed using the three α-ages in Figure 1, and fixed chronological age 65, West Germany, Japan, Russia, and the United States, c. 1950–c. 2010



NOTE: Spline smoothing.
SOURCE: Human Mortality Database (accessed February 1, 2012) and authors' calculations.

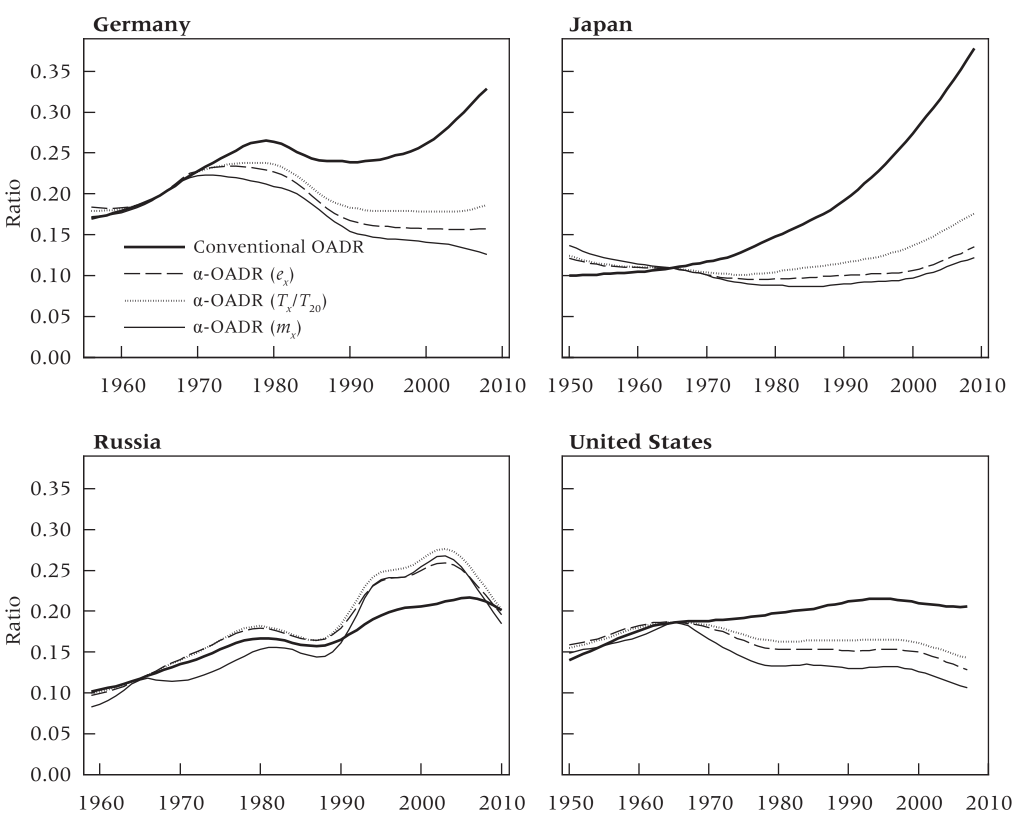
ages. (For example, when $h_{a,t}$ is an indicator variable that takes on the value of unity when age is 65+, we obtain the standard proportion of the population 65+ years old.) *Elder ratios* differ from elder proportions by excluding from the denominator people with the characteristic associated with the elderly. A special subset of elder ratios, α-old-age dependency ratios, α*OADR*, is based on indicator variables constructed from threshold α-ages:

$$\alpha OADR = \Sigma_a s_{a,t} h_{a,t} / \Sigma_a s_{a,t} (1 - h_{a,t}), \qquad (4)$$

where the summation is from some initial age, often 15 or 20, to the maximum age. When $h_{a,t}$ is an indicator variable that takes on the value of unity when age is 65+, we obtain the standard old-age dependency ratio (OADR).

Figure 2 shows elder proportions for the four countries, where the $h_{a,t}$ are indicator variables based on the α-ages shown in Figure 1. Although the

FIGURE 3 α-old-age dependency ratios (α-OADR) computed using the three α-ages in Figure 1, and conventional old-age dependency ratio (OADR), West Germany, Japan, Russia, and the United States, c. 1950–c. 2010



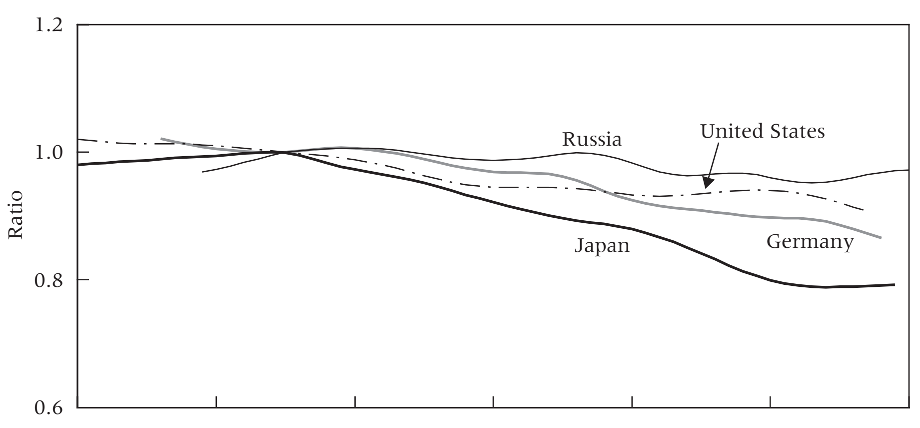
NOTE and SOURCE: As for Figure 2.

proportions 65+ rise in all countries, the most recent observations of the characteristic-based elder proportions in Germany and the US are lower than they were in 1970. Adjusting for the changing characteristics of the population allows us to see that in some ways the populations of Germany and the US have been growing functionally younger.

To illustrate elder ratios, in Figure 3 we show the conventional OADR and α-OADRs for the four countries based on the three threshold α-ages shown in Figure 1. The conventional OADR in Japan increased rapidly, but all the other α-OADRs show much more modest aging. In the US, the conventional OADR rises from 1965 onward, while the adjusted ones generally fall. The characteristics-based approach to aging provides a natural framework for seeing these differences.[2]

Elder relationships have the form $\Sigma_a s_{a,t} h_{a,t} / \Sigma_a s_{a,t} j_{a,t}$, where $h_{a,t}$ and $j_{a,t}$ refer to two different characteristics. An example of an elder relationship is provided in Figure 4. There $h_{a,t}$ and $j_{a,t}$ are indicator variables based on the α-ages in Figure 1. The $h_{a,t}$ are set to unity when age is greater than the α-age threshold associated with a remaining life expectancy of 15 years, and the $j_{a,t}$ are set to unity when age is greater than the α-age threshold associated with pension receipt (the life-course ratio, in the context of our idealized pension system). Figure 4 shows that these ratios have been decreasing over time after 1970, even for Russia. This indicates that over time fewer and fewer people receiving pensions under such a system would be considered old. Elder relationships are natural quantities to compute in the framework of a

FIGURE 4 Elder relationships computed using the number of the population at or above the α-age associated with e_x in the numerator and the number of the population at or above the α-age associated with the life-course ratio in the denominator, West Germany, Japan, Russia, and the United States, c. 1950–c. 2010



NOTE and SOURCE: As for Figure 2.

characteristic-based approach to the study of population aging, but, to our knowledge, none have previously appeared in the literature.

Elder proportions, elder ratios, and elder relationships are only three ways of incorporating changing characteristics into the study of population aging. There are clearly others—for example, as in Heigl (2002). The hallmark of the characteristics approach to the measurement of population aging is the consistent use of changing characteristic schedules together with changing age structures, regardless of the exact way in which the two are combined.

Implications for research and policy

Much research on population aging has been based on conventional measures. Allowing for alternative definitions of age and aging can help make the conclusions of this literature more robust. Sinn and Uebelmesser (2002), for example, argued that Germany could become a gerontocracy by 2016 because by that time there would be more voters with an incentive to vote against pension reform than there would be to vote for it. But their analysis was based on an unchanging full pension age, whereas the full pension age in Germany is already scheduled to rise from 65 to 67 and might well rise further. Our old-age threshold based on the life-course ratio is a simple way to include plausible changes in full pension ages into such analyses.

Other studies that use conventional aging measures include Kelley and Schmidt (2005), exploring dependency ratio effects on economic growth, and Börsch-Supan, Heller, and Reil-Held (2011), examining the relationship between social cohesion and aging. The former finds a significant youth dependency effect but not an old-age dependency effect; the latter finds no adverse aging effect on social cohesion. Since, as we show in Figure 3, the conventional old-age dependency ratios and their α counterparts can behave quite differently, it would be worth revisiting such studies using the characteristics approach.

α-ages can also be used in place of chronological ages in investigations of health care costs. In any year, older people generally require more health care than younger ones. In many countries, health care expenditures are particularly high in the last few years of life. With life expectancy improvements, these high-cost years are deferred to older ages. Forecasts of health care expenditures that do not take into account the changing life expectancy of the population overestimate the increase in health care costs (Bjorner and Arnberg 2012; Felder 2012; Martin, Gonzalez, and Garcia 2011; Cutler et al. 2007). A simple approach to forecasting future health care expenditures would be to forecast them on the basis of remaining life expectancy.

Taking the changing characteristics of people into account when studying population aging is a simple and natural way to reassess past research and introduce new perspectives on important policy questions. The approach we have discussed in this article reconceptualizes age based on the characteristics of people and allows the construction of new multidimensional measures of aging. The study of population aging based simply on chronological age, familiar for over a century, has been extremely useful for most of this period. We believe, however, that the characteristics approach set out here is more appropriate for dealing with the kinds of demographic change now underway.

Appendix: Hypothetical calculations of α-age based on life expectancy

Table A.1 shows hypothetical life expectancies between the ages of 65 and 67 over the period *t* to *t+5*. Suppose that we were looking for α-ages corresponding to a remaining life expectancy of 15 years. In this case, we would find the ages corresponding to a life expectancy of 15 years in each column.

TABLE A.1 Hypothetical life expectancies (e_x) between ages 65 and 67 for the years *t* through *t+5*

	Year					
Age	*t*	*t+1*	*t+2*	*t+3*	*t+4*	*t+5*
65.0	**15.00**	15.20	15.40	15.60	15.80	16.00
65.1	14.95	15.15	15.35	15.55	15.75	15.95
65.2	14.90	15.10	15.30	15.50	15.70	15.90
65.3	14.85	15.05	15.25	15.45	15.65	15.85
65.4	14.80	**15.00**	15.20	15.40	15.60	15.80
65.5	14.75	14.95	15.15	15.35	15.55	15.75
65.6	14.70	14.90	15.10	15.30	15.50	15.70
65.7	14.65	14.85	15.05	15.25	15.45	15.65
65.8	14.60	14.80	**15.00**	15.20	15.40	15.60
65.9	14.55	14.75	14.95	15.15	15.35	15.55
66.0	14.50	14.70	14.90	15.10	15.30	15.50
66.1	14.45	14.65	14.85	15.05	15.25	15.45
66.2	14.40	14.60	14.80	**15.00**	15.20	15.40
66.3	14.35	14.55	14.75	14.95	15.15	15.35
66.4	14.30	14.50	14.70	14.90	15.10	15.30
66.5	14.25	14.45	14.65	14.85	15.05	15.25
66.6	14.20	14.40	14.60	14.80	**15.00**	15.20
66.7	14.15	14.35	14.55	14.75	14.95	15.15
66.8	14.10	14.30	14.50	14.70	14.90	15.10
66.9	14.05	14.25	14.45	14.65	14.85	15.05
67.0	14.00	14.20	14.40	14.60	14.80	**15.00**

The table of α-ages would then be:

Year	**α-ages**
t	65.0
t+1	65.4
t+2	65.8
t+3	66.2
t+4	66.6
t+5	67.0

Notes

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1 For analogous calculations of α-age trajectories for other characteristics of population aging, see Shoven and Goda 2010; Siegel 2011; and Cutler et al. 2007. For cases where the level of the characteristic is changing over time, see Sanderson and Scherbov 2005; Lutz, Sanderson, and Scherbov 2008; and Sanderson and Scherbov 2008.

2 Elder ratios can use levels of the characteristics themselves rather than indicator variables. Examples include the Adult Disability Dependency Ratio (ADDR) (Sanderson and Scherbov 2010), which uses time-varying rates of severe disability, and the Cognition-Adjusted Dependency Rate (CADR) (Skirbekk, Loichinger, and Weber 2012), which uses a measure of cognition for people aged 50+.

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