Rescaling the Life Cycle: Longevity and Proportionality

RONALD LEE
JOSHUA R. GOLDSTEIN

Since 1900 life expectancy in the United States has increased by about 30 years, from 48 to 77 years. Most projections foresee continued increase at a slower rate, reaching 85 or 90 years by 2100 (Lee and Carter 1992; Tuljapurkar et al. 2000). Some analysts foresee the possibility of far greater life expectancy increases—to 100, 150 years, or more (Manton et al. 1991; Ahlburg and Vaupel 1990; Schneider et al. 1990). Individuals welcome longer life, but for populations, increases of this magnitude could impose heavy costs on the working-age groups and could have other substantial but uncertain economic and social consequences. These consequences will depend in large part on how the additional expected years of life are distributed across the various social and economic stages of the life cycle. This chapter speculates about how the gains will be used and how the life cycle will be modified.

Proportional rescaling of the life cycle, in which every life cycle stage and boundary simply expands in proportion to increased life expectancy, provides a convenient benchmark. Under proportional rescaling, if longevity doubles, then so would childhood, the length of work and retirement, the span of childbearing, and all other stages of the life cycle. Proportional rescaling of the life cycle would appear to be neutral in some sense, so that life, society, and economy could continue as before, except that there would be proportionately more time spent in every stage. However, we will find that while this is (or could be) true for some aspects of life, other aspects would vary with the square or some other power of longevity.

Although proportional rescaling may seem natural, and indeed does occur in nature as we discuss, powerful forces impede its application to humans. First are biological constraints related to human development, such as menarche and menopause, even though our vigor and health may advance with longevity. Second are institutional constraints, for example on schooling and retirement. Although these may adjust in the long run, over shorter horizons they may block proportional rescaling. Third, stock-flow inconsistencies may cause human and physical capital to rise with longevity more rapidly than labor force size, causing wages and incomes to rise and the interest rate and returns to human capital to fall, triggering further adjustments. If time in retirement is a luxury, then it may rise rapidly as incomes rise, so that age at retirement does not rise in proportion to longevity—as in fact it has not. For these and other reasons, we should not actually expect to observe proportional rescaling in connection with increased life span in the past, nor should we anticipate it for the future. Nonetheless, proportionality is a useful benchmark against which to compare past changes and the hypothetical future.

What would proportional rescaling look like?

A perfectly proportional rescaling of the life cycle accompanying increased life expectancy would appear indistinguishable from the effect of a simple change in the units of measurement of age/time, as if we had changed from dollars to pesos or from inches to centimeters. For example, suppose that an original 75-year life cycle were instead measured in units of six lunar months, or half-years. The new life cycle would be 150 units long instead of 75, but of course nothing would be different. (We use doubling as a convenient example, but we believe that a 15 percent increase in life cycle is more likely for the twenty-first century.) Every life cycle stage would last twice as long as before, measured in the new units. Every rate would be only half as great, since only half as many events would take place in 6 months as in 12 months.

Proportional life cycle changes can occur in both strong and weak forms. In the strongest form, the change affects not only the average timing of life cycle transitions but also the whole distribution of timing within a population. Thus, for example, the spread around the mean age of death or mean age of childbirth would also double if the mean age of death doubled. We call this "strong proportionality," which can apply both to the distribution of an event among the individuals in a population and to the timing or level of an event in the individual life cycle. If the change in life cycle timing is only proportional with respect to the mean ages of each life cycle transition or stage, then we call this "weak proportionality." Weak proportionality would occur if, for example, as longevity increased, the mean age of reproduction increased proportionately but the variance of the net maternity function stayed constant.

It is important to distinguish between "flow" or "rate" variables, which are measured per unit of time, and "stock" variables, which are not. Completed fertility, accumulated wealth, the probability of ever marrying, or of ever having a first birth, are all examples of stocks. Birth rates, death rates, wage rates, income, and rate of knowledge acquisition are flows, all measured per unit of time. Under the perfectly proportional rescaling of the life cycle discussed above, all stocks are unchanged, provided they are assessed at the same proportional stage of the life cycle (for example at the age equal to 60 percent of life expectancy). In a population with a life expectancy twice as great, the net reproduction rate (NRR) would not be twice as high; it would be unchanged. All flow or rate variables, however, would be reduced in inverse proportion to the increase in longevity. Adding these reduced rates across twice as long an age span of reproduction would then yield an unchanged completed fertility.[1] We might say that perfectly proportional rescaling of the life cycle is always "stock constrained," in the sense that the magnitude of stocks is preserved under rescaling.

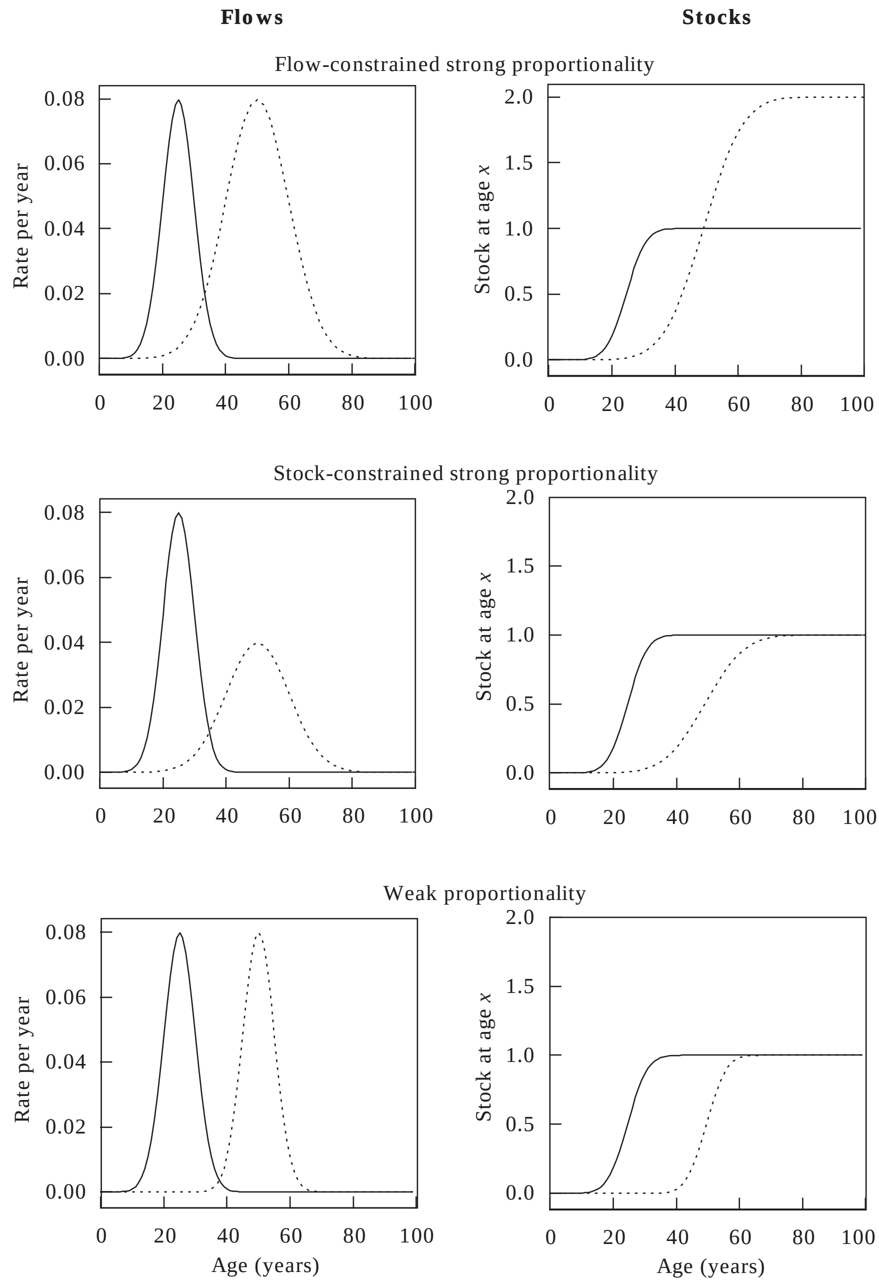
In some cases, this kind of stock-constrained rescaling is not an interesting scenario to contemplate. For example, if people were to live twice as long, we would not expect that at each age they would earn only half as much, or that they would learn only half as much during each year in school. In these cases, it is more natural to assume that the rate of productivity, or earning, or acquisition of knowledge, remains constant, so that the stock of lifetime earnings, or completed education, would double. Such cases we call "flow constrained."

Figure 1 illustrates some hypothetical examples of what proportional rescaling would look like under different assumptions, all of which assume the convenient, yet implausible doubling of longevity. The top row illustrates strong proportionality with stock constraints, such as might be the case with fertility. Here the ages at which flows occur are doubled, but at the same time the flow itself is halved. The result is that lifetime completed fertility remains unchanged, although the age at which a given cumulative fertility is achieved is doubled. The middle row shows strong proportionality with flow constraints, such as might be the case with earnings. The age at which a given flow occurs in the rescaled age profile is twice that of the original profile. Keeping flows constant over a longer period of time, however, produces a doubling of the stock, for example cumulative lifetime earnings (and perhaps derived stocks, such as lifetime savings, which we discuss later). The bottom row illustrates a particular case of weak proportionality. Here the mean age of the flow doubles from 25 to 50, but the width of the age profile does not expand proportionally.

Proportional rescaling in nature

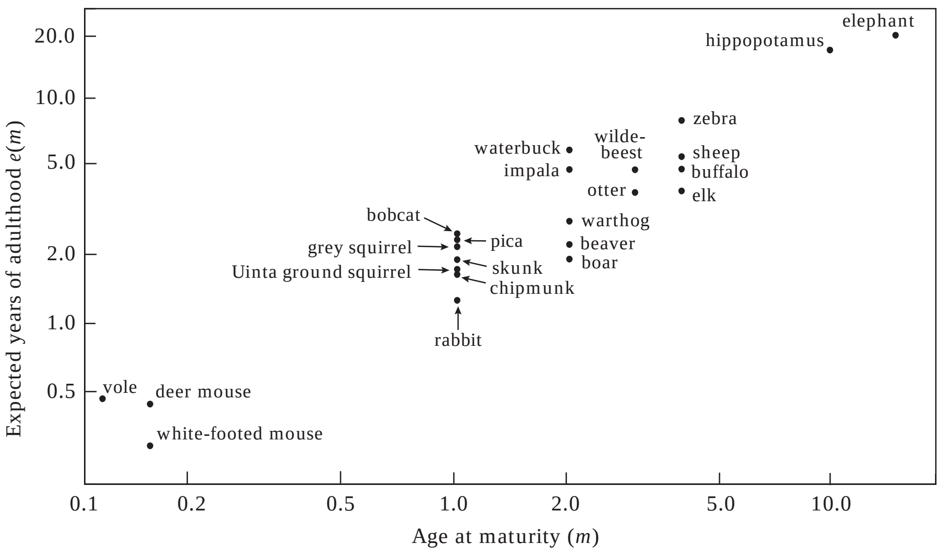
The object of this chapter is to explore the feasibility of proportional rescaling within a single species, namely humans. A large body of work already exists looking at proportional rescaling between biological species. In biology this falls under the study of "biological invariants" (Charnov 1993). Figure 2 shows

FIGURE 1 Illustrative examples of proportional rescaling under a hypothetical doubling of longevity



NOTES: Original age profile is shown as a solid line, rescaled profile as dashed line. Stocks at age *x* are the integral of flows from age zero to *x*. In this figure, flow-constrained strong proportionality is obtained by doubling ages at which a given rate is originally observed, resulting in a doubling of eventual stocks; stock-constrained strong proportionality is obtained by simultaneously doubling ages and halving flows; and weak proportionality is obtained by doubling the mean of the flows while keeping the standard deviation of flows unchanged.

FIGURE 2 An example of proportional rescaling in nature: Age at maturity versus expected life as a mature adult in 23 mammalian species (logarithmic scales)



NOTE: Data from Millar and Zammuto 1983.

an example of such an invariant across mammalian species: the relationship between age at physical maturity (m) and expected years of adulthood $e(m)$. Goldstein and Schlag (1999) show a similar figure for the relationship between mean age of reproduction and life expectancy at birth. Other examples of biological invariants include the ratio of body mass to life expectancy at birth; the product of the number of offspring and the chance of survival to the mean age of reproduction; and metabolic invariants (Austad 1997). "Invariant" is used by biologists not as a rule to which there are no exceptions but rather to describe general tendencies, with variation around them. In many cases, the rescaling involves a power transformation and is therefore not proportional. For example, body mass rises approximately with the cube of body length, so if body mass is proportional to life expectancy, then body length will not be. Note, however, that in equilibrium every animal population will have a net reproduction rate of unity, so this stock measure will be invariant across species, consistent with proportional rescaling.

Biological invariants result from evolutionary forces, and explanations for them are given in terms of evolutionary theory and maximization of reproductive fitness. The increased longevity of modern humans has not resulted from natural selection. It is the result of scientific advances, changes in life style, social organization, nutrition, and manmade environments. For this reason, we would not expect the biological invariants in nature to apply to human life cycle timing as we live longer. Still, the analogy is useful, because the optimizing principle still obtains even if what is being optimized is not reproductive fitness, but rather a more general notion of utility that might include economic as well as reproductive success and hedonic consumption as well as productive investments.

Furthermore, it appears that the evolution of proportionally related life cycles across species is not a result of independent adaptations across a range of traits but is rather linked to some underlying biological mechanisms that control the rate of metabolism and other features of the life cycle clock (e.g., Carey et al. 1998; Finch 1990; Biddle et al. 1997; Lin et al. 1997). Evidence for this includes the ability to breed longer-living animals simply by the selective breeding of individuals that reproduce late in life. The result is that both the onset of reproduction and the age at death are proportionally delayed. Restricted diets in the laboratory appear to have a similar effect, delaying mortality but also delaying physical maturity. Finally, some genetic modifications appear to have proportional effects on longevity and the timing of reproduction.

Life table stretching and the proportional life cycle

We can divide the human life cycle into stages of childhood, working ages, and old age, marked approximately by the boundaries of age 15 or 20 and 60 or 65. When life expectancy increases in a population, person-years of life are added to the life table within each of these three life cycle stages, not only at the end of life in old age. This is not a natural way to think about the lives of individuals; for individuals, alterations in length of life seem always to come at the end. But that is only so ex post; ex ante, individuals are subject to risks of death at every age, and therefore their expected years of life at each age throughout the potential life cycle are subject to modification when these risks change.

Historically, we can observe at what ages person-years of survival are added when life expectancy at birth has risen. When life expectancy has risen by one year from a low level such as 20, this one year has been distributed as follows: 0.7 years between 15 and 65; 0.2 years between 0 and 15; and only 0.1 year after 65. As life expectancy rises further, the incremental gains in childhood and the working ages decline, and the gains in old age rise. Further increases from the current life expectancy level of 77 years in the United States will be concentrated in old age, with 0.7 years coming after age 65 and hardly any coming before age 15 (Lee 1994; Lee and Tuljapurkar 1997).

Increasing survival does not affect all stages of life equally. A mechanical reason for this is that in the above calculations we have not rescaled the age boundaries of youth and old age as longevity increased. But even if these boundaries were rescaled, historical improvements of mortality have been inconsistent with proportional rescaling. Mortality has declined faster in infancy than over the rest of the life cycle, and this has resulted in nonproportional changes in the survival curve.

As with all other aspects of the life cycle, we can visualize strong proportional change by asking what would happen if we simply changed the units of measuring age, say to 6-month units. Then for the proportion of survivors, or for life expectancy, values would be attained at age x that were previously attained at age $x/2$. The higher the age in the initial life table, the farther out we would have to move on the new age scale to reach a corresponding level. For age $x=3$, the new age would be 6; and for age $x=60$, the new age would be 120. (Death rates would be shifted in the same way, but also proportionately reduced, as discussed earlier.)

To state this is to see that historical shifts have not corresponded to this simple assumption. Fries (1980) emphasized that the actual pattern of mortality change is of the opposite sort, and called it "compression of morbidity." When mortality declines, the upper end of the $l(x)$ curve shifts relatively little, rather than relatively more as required by strong proportionality. Indeed, some observers suggest that the maximal length of life (first x such that $l(x) = 0$) has hardly changed at all in recent centuries. Wilmoth et al. (2000), however, show that the age of the oldest death in Sweden has been rising at least since 1861, accelerating in recent decades; since 1970, it has been rising at about the same speed as life expectancy (Wilmoth and Robine, in this volume.)

One useful diagnostic is to look at the $l(x)$ value for some age x in 1900, for example, and find the corresponding age at which that $l(x)$ value is reached in 1995.[2] Calculation shows that comparing US mortality in 1900 and 1995, the drop in survivorship reached at age 1 in 1900 was not matched until age 59 in 1995, an age increase of 5,800 percent. The corresponding increases at ages 30, 60, and 90 were 137 percent, 33 percent, and 10 percent. Under strong proportionality, these percent increases would be equal at all ages. We have made similar calculations for the projected survivorship changes between 1995 and 2080, based on the mortality projections of the Social Security Administration. The drop in survivorship reached at age 1 in 1995 will not be matched until age 23 in 2080, an age increase of 2,200 percent. The corresponding increases at ages 30, 60, and 90 are 50 percent, 13 percent, and 5 percent.

We can get some analytic insight into the likely pattern of mortality change in the future by drawing on a simple result from Vaupel (1986). Suppose that mortality after age 50 follows Gompertz's Law, with death rates rising across age at a constant exponential rate θ = 10 percent per year. Suppose further that death rates at each age over 50 decline over time at ρ = 1 percent per year. With these assumptions, mortality at ages over 50 declines in such a way that the mortality curve shifts r/q years to the right every year.[3] With values of $r = .01$ and $q = 0.1$, the mortality curve shifts 0.1 years to the right every year; and every decade, the death rate previously experienced at age x will now be experienced at age $x+1$. Once mortality decline has proceeded to the point where survival to age 50 is close to unity,[4] then the survival curve and life expectancy will be displaced to the right by one year each decade, at every year of age. Because this shift to the right is equal across all ages over 50, rather than increasing in proportion to age, it is not strictly consistent with proportional stretching.

Under proportional stretching of the life cycle, the time spent disabled or in ill health would rise in proportion to longevity, as would the time spent free of disability. Recent research on disability, chronic illness, and functional status reveals patterns that are broadly consistent with such proportional changes, at least for the last two decades in the United States (Costa 2000; Crimmins et al. 1997; Manton et al. 1997; Freedman and Martin 1999; Manton and Gu 2001).[5] For example, Crimmins et al. (1999) conclude that persons in their late 60s in 1993 are functionally like those in their early 60s in 1982.[6] Research (Lubitz and Prihoba 1984; Lubitz et al. 1995; Miller 2001) also shows that health care costs in old age are more closely related to time until death than to chronological age, so that as life expectancy rises and fewer persons at any age are near death, health care costs would fall, other things being equal. All these findings are qualitatively consistent with proportional rescaling of the life cycle for health, functional status, and disability; but because of imprecision of measure they are also consistent with compression of morbidity, with disabled years shrinking as a proportion of the life cycle.

Individual demographic aspects of rescaling

Mortality, survival, health, and longevity are the bare bones of the life cycle. Now we enrich the story by discussing fertility and other social behavior.

Transitions to adulthood: Education, marriage, and the onset of childbearing

In animals, the life cycle stage is often divided into infancy and maturity and is closely tied to physical growth and sexual maturity (Kaplan 1997). In humans, the transition to adulthood is typically seen as being much more complicated, involving a change in social, economic, and familial roles (Modell et al. 1976; Marini 1987). Sexual maturity is only the beginning of the transition to adulthood, which may be completed when children are economically and residentially independent of their parents, get married, and begin families of their own.

Some easily measured indicators of the transition to adulthood include the age of educational completion, first marriage, and first birth. Table 1 shows the pace of change of the mean ages of these indicators for several industrial countries between 1975 and 1995. Education, marriage, and childbearing are all being postponed at a rapid pace in the United States, Japan, and Sweden.[7] The rates of rescaling vary by indicator, but all are faster than the pace of longevity increase. Whereas life expectancy at birth is increasing roughly 0.2 percent per year, mean age at first birth is increasing about twice as fast, and mean age at first marriage perhaps four times as fast.

The differential rates of rescaling of education, marriage, and fertility mean not only that the transition to adulthood as a whole is being shifted to later ages but also that the interrelations between the various components of the transition are changing. For example, the faster pace of marriage postponement than of first births is evidence of the increase in premarital births and the rise of cohabitation in the United States and Sweden. The synchrony in marriage and birth postponement in Japan is due in part to low levels of premarital childbearing in that country.

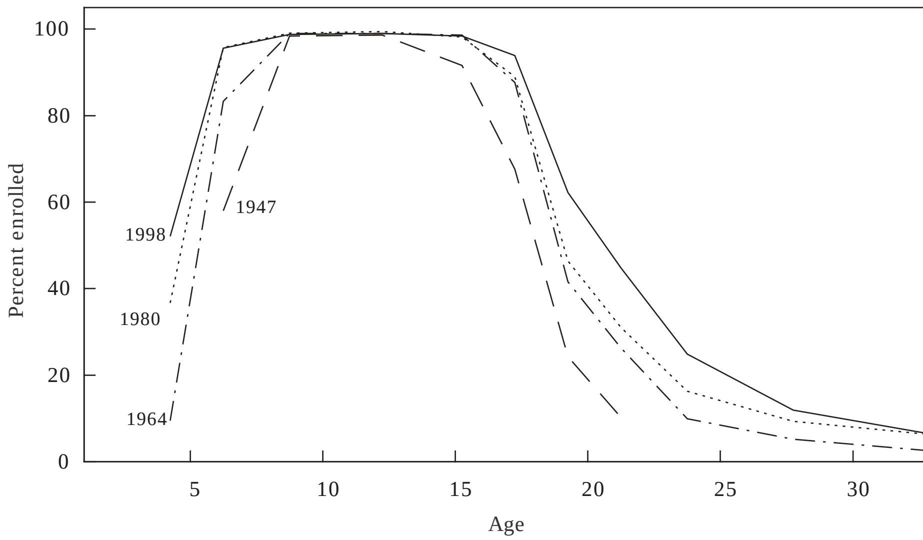
The changing age profile of educational enrollment over the last half-century in the United States shows dramatic increases at both older and younger ages. Figure 3 shows the percent enrolled in school by age group among the civilian noninstitutionalized population. We see massive increases in enrollments in both the youngest age groups (3–4 and 5–6 years) and the older age groups (above age 21). For older ages, the increases in enrollment correspond nicely to the proportional stretching scenario. The increases in enrollment at younger ages, however, are not at all consistent with the proportional stretching argument, according to which the first ages of enrollment should be increasingly postponed over time. One explanation of increased enrollment at younger ages is that it represents not so much a

TABLE 1 The pace of rescaling of selected life cycle indicators in the United States, Japan, and Sweden: Annual rates of change (in percent), 1975 to 1995

Country	Life expectancy at birth (females)	Mean age at first birth (women)	Mean age at first marriage (women)	Mean age at end of school enrollment (both sexes)
United States	0.1	0.4	0.9	0.5
Japan	0.4	0.3	0.3	0.3
Sweden	0.2	0.5	0.7	NA

NOTES: (1) US ages at first birth and first marriage are period medians. (2) Mean age at end of school enrollment is calculated from period enrollment rates. The mean age is estimated as $m = \text{sum}(nEx * n) + x0$, where nEx is the enrollment rate for the age group x to $x+n$ (e.g., 31.9 percent for 20- and 21-year-olds in 1970), n is the width of the age group, and $x0$ is the youngest age group of full enrollment (age 6 in the US data). For Japan, entrance rates to high school, junior college, and university were available. The mean age at end of school enrollment was estimated as m = 14 + (4 * HS entry) + (2 * HS entry * Jr. college entry) + (4 * HS entry * university entry).
SOURCES: Japan (1999, 2000); Sweden (1995); NCHS (2000).

FIGURE 3 Educational enrollment rates in percent of civilian noninstitutionalized population by age: United States 1947, 1964, 1980, and 1998



SOURCE: US Census Bureau, Current Population Survey. (http://www.census.gov/population/socdemo/school/taba-2.txt)

change in the timing of the educational stage of the life cycle as an institutional shift from the private sphere of home education of infants to the public sphere of day care and kindergarten. Still, if entry into a socializing environment (being surrounded by nonfamily members) is thought to be part of the transition from infancy to childhood, early enrollments represent an acceleration in life cycle timing.

While some of the transitions that signify the completion of entry into adulthood, such as marriage and childbearing, are being delayed, many are being advanced to younger ages. Biologically, the long-term trend, until recently, has been earlier ages at menarche and physical maturity (Eveleth and Tanner 1990). Legally, the trend worldwide is for voting rights to be extended to younger ages.[8] Adult criminal penalties in both the United States and Japan are increasingly being extended to minors. Socially, precociousness appears to be the rule rather than the exception, with children allowed various forms of independence at increasingly younger ages.

Whereas half a century ago transitions to maturity were compressed into a narrow age span, the transition appears to be becoming more diffuse. Children who move away from their parents increasingly return home (Goldscheider and Goldscheider 1999). Education, labor force participation, and the establishment of new families are often less clear-cut stages than they once were. People in their 20s and 30s may be working, going to school, receiving support from their parents, and starting a family of their own—all simultaneously rather than in a series of ordered steps.

What are the implications of an expansion of early adulthood? One result is a mismatch, at least temporarily, between certain life cycle–linked institutions and the life cycle timing of individuals. As an example of this, in the United States young adults can find themselves without health insurance because they are too old to be covered by their parents' plans but are not yet economically secure enough to have their own plans.

A second consequence of a longer transition to adulthood is more time for career and partner searches. Social and sexual interactions with potential spouses may now last a decade or more. Likewise, career experimentation and repeated exit from and entry to education are possible thanks to less time pressure to support a family and achieve economic independence. Because the efficiency of searches probably remains constant per unit of calendar time (i.e., searches are flow constrained), the quality of searches should, all other things equal, improve.

A third consequence is the inversion of traditional sequences (Rindfuss et al. 1987). A traditional sequence in the first half of the twentieth century might have been: educational completion, departure from parents' home, entry into labor force, marriage, and childbearing. Now, with the extended time of the transition and the moving back and forth between transitions, childbearing may precede marriage; entry into the work force may precede leaving the parental home; divorce may be followed by moving back to the parents' home. The extended time over which the various transitions to adulthood occur allows greater opportunity to reverse transitions and to change their order.

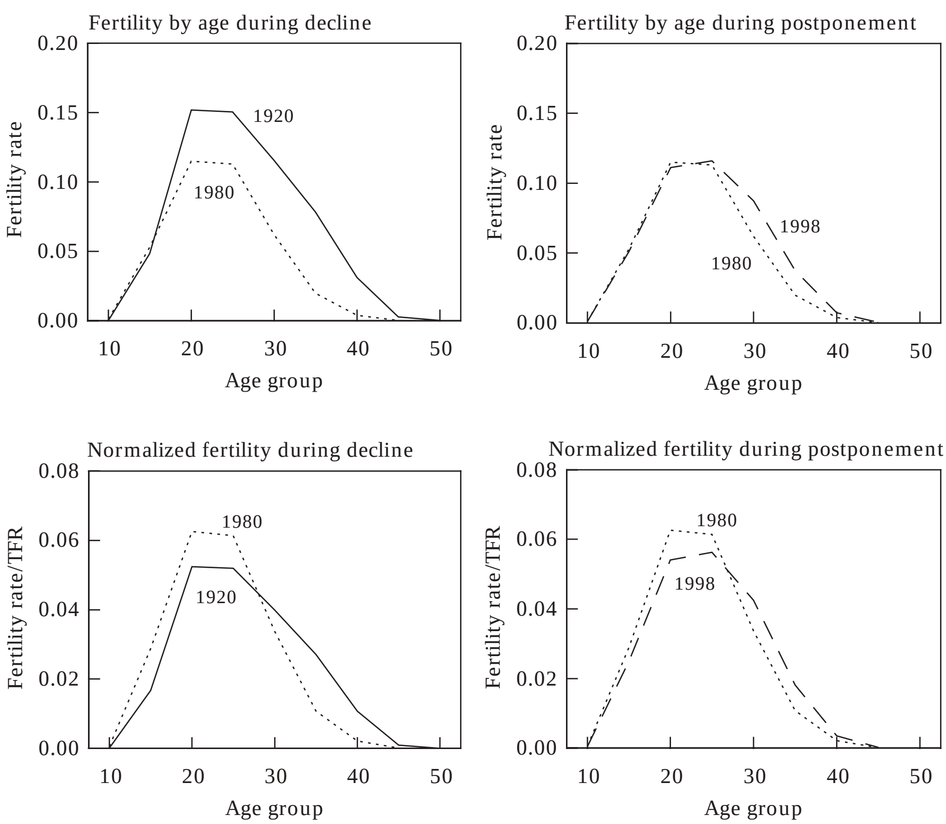
From the point of view of a rational life cycle planner, an extended period of quasi-adulthood probably makes sense for those who can expect to live a long time. A long investment horizon makes it worthwhile to invest more in one's own human capital and stay in school longer. Likewise, it makes experimentation less costly and potentially more rewarding. It is not clear whether time spent by 20- and 30-year-olds who have not yet committed themselves to careers or to families is a productive human capital investment or leisure (a kind of pre-career retirement). In some sense, it may be both. The prolonged period of transition to adulthood may be akin to the wrestling of young chimpanzees, who look to us as if they are just playing but are actually learning skills that will be useful and necessary to them as adults.

Fertility

Over the course of the last century, increased longevity has been accompanied by declines in total fertility, without a consistent change in the mean age of childbearing.[9] Delays in the timing of the first birth have been counterbalanced by an earlier end of childbearing as the level of fertility has declined. In recent decades, however, both the onset and end of childbearing have been slowly shifting to older ages. A continuation of this trend is consistent with proportional stretching of the life cycle, but from a theoretical perspective it is difficult to make firm predictions about either the timing or the amount of fertility that will be associated with longer life.

As an example of the pattern of fertility change over the last century, Figure 4 shows age-specific fertility rates for women in the United States in 1920, 1980, and 1998. The upper panels show the unadjusted age-specific fertility rates and the lower panels show the same age pattern, but normalized so that all of the curves have the same fertility level over the life cycle. The figure indicates that as fertility declined from 1920 to 1980, the timing of childbearing became more concentrated in the 20 to 25 year age group.

FIGURE 4 Period age-specific fertility profiles of US women: 1920, 1980, and 1998



NOTE: Normalized profiles are obtained by dividing the age-specific rates in a given year by the total fertility rate in that year.

This was a result of declining fertility at both younger and older ages. Since 1980, however, the whole distribution of fertility has shifted slightly to older ages. This recent shift is consistent with proportional change, in that birth rates at older ages are increasing faster than at younger ages.

Some believe that further increases in age at first birth will not be accompanied by a proportional increase in the age at the end of childbearing. As a result the distribution of childbearing will be compressed to a narrower band of the life cycle, increasingly between the ages of 30 and 40 years. One reason for believing such an assessment is the biology of female reproduction and the onset of menopause, in which there has been little if any recorded change in the last century. A counterargument is that if biological advances can extend life, then advances in reproductive technology can extend childbearing. Already, the ability to store eggs and sperm, as well as frozen embryos, suggests that parents can have children at arbitrarily late ages with the present technology. In the future, it may well be possible for women to conceive, gestate, and give birth to children at older ages. It does not seem a priori a more difficult problem to increase the age of women's maximum reproduction than to increase the age of maximum longevity.

In the near term, proportional increases in the mean age of childbearing—weak proportionality—are possible even without advances in reproductive technology. For example, if female life expectancy were to increase 25 percent to 100 years, the same proportional increase would require a mean age of childbearing of 35, well within the realm of current biology.

Would later childbearing reduce total fertility? Timing may have a direct effect on the level of fertility, particularly if delays in the onset of fertility are not accompanied, because of biological limits, by higher fertility at older ages. But later childbearing may also influence the demand for children.

Proportional rescaling could increase the costs of childbearing, both the direct costs like children's education and the indirect costs like the earnings and promotion opportunities forgone (Willis 1973; Calhoun and Espenshade 1988). Parents have higher potential earnings at older ages, so later births have a higher opportunity cost as participation in the labor force is curtailed. Opportunity costs of childbearing will depend in part on how the age-earnings curve is rescaled. But in some careers (e.g., academia and law firms) job security increases with age as a result of institutional practices such as tenure. It may actually involve less sacrifice for some people to have children at older ages, depending on institutional arrangements. Also, discounting will reduce the opportunity costs of later-born children.

Higher forgone earnings may be more than offset by higher lifetime earnings, and the relative costs of childbearing may decrease. Furthermore, if the spacing of children does not change, there might be a substantial decline in the relative costs of bearing, say, two children. Consider a woman who lives 75 years and has two children 3 years apart. She will be the mother of children less than 3 years old for a total of 6 years out of her 75-year life span. On the other hand, a woman who lived to be 100 and had the same number of children with the same spacing would still only spend 6 years of her life with infants. In this case the nonproportional change of the length of infancy resulting from the flow-constrained nature of human growth may change the relative cost of childbearing.

Population-level implications of rescaling

The overlap of generations

Under perfect proportionality, population size and structure remain unchanged (Goldstein and Schlag 1999). However, if the mean age of reproduction does not change at the same pace as longevity, then population size, the overlap of generations, and dependency ratios will be affected.

Consider a stylized life cycle in which childhood lasts until age 30, retirement begins at age 60, and everyone dies at age 90. Let reproduction occur at age 30 and the population be stationary. In this case, three generations will be alive at once, individuals will spend one-third of their life working, and the total dependency ratio for the population as a whole will be 2:1. Under proportional rescaling, say a doubling, none of these population characteristics would change; population size would also remain constant.

If, on the other hand, longevity increased without changing generational length, more generations would be alive at once and the total population size would increase. Such a nonproportional change would increase the share of life spent between childbearing and retirement and would also change the total dependency ratio of the whole population. If we doubled the length of life and the age of retirement as above but without changing the age of reproduction, the number of generations alive at once would increase from three to six, the population size would double, and the total dependency ratio would shrink from 2:1 to 1:1. Nonproportional changes in generation length could also occur in the reverse direction. If generation length increases faster than longevity, the result is a decline in population size and, if childbearing still signals the entry into adulthood, an increase in the dependency ratio.

Is rescaling a solution for subreplacement fertility?

While the above discussion has assumed replacement-level fertility, it is perhaps of greater practical interest to consider how rescaling of the life cycle might offset population aging that accompanies below-replacement fertility. For example, age 65 in a stationary population might be mapped to age 70 in a shrinking population, in order to keep retirees a constant proportion of the entire population.

The nonlinearity of the age pyramid means that changes in population growth rates cannot be offset by proportional rescaling of the life cycle. Taking the United States life table of 1992 as an example, Table 2 shows the stable age pyramid for two cases: a population growth rate of zero and a negative growth rate of 1 percent (equivalent to a total fertility rate of about 1.5). By redefining ages, we can distort the subreplacement fertility age pyramid so that it has the same shape as the replacement-fertility age pyramid.

This table indicates the ages at which each decile of the population age distribution is reached. Thus, in the stationary population 10 percent of the population is under age 6.7 years, while in the subreplacement population all children under age 10.2 years are needed to fill the first decile. The table also shows that the kind of restructuring of the life cycle that would be needed to offset a shift to subreplacement fertility is not proportional. The column labeled "ratio of ages" shows that more rescaling would be needed at younger ages than at older ages. The age below which 90 percent of the population will find itself shifts from 73.4 years to 77.9 years, a change of only 6 percent as opposed to the more than 50 percent rescaling that would be needed at younger ages. The table also shows the absolute difference in ages that would be required by rescaling. Here we see that the greatest changes would be needed in the middle of the life cycle, shifts of about 8 years, or about twice the magnitude of the shifts at the two extremes of the life cycle.

A striking and counterintuitive result is that less proportional rescaling would be needed at older ages than at younger ages. We might interpret this optimistically, since it is presumably hardest to make large changes at older ages.

TABLE 2 Rescaling implied by a change in population growth rates. Ages corresponding to cumulative deciles in a stationary population (r = 0) and in a declining population (r = –.01). Proportional and absolute rescaling implied by change in growth rate

Percentile	Age r = 0	Age r = –.01	Ratio of ages	Difference of ages
0.1	6.7	10.2	1.52	3.51
0.2	14.4	20.3	1.41	5.91
0.3	22.2	29.6	1.34	7.43
0.4	30.0	38.2	1.27	8.20
0.5	37.9	46.2	1.22	8.34
0.6	45.9	53.9	1.17	7.95
0.7	54.2	61.4	1.13	7.15
0.8	63.0	69.1	1.10	6.02
0.9	73.4	77.9	1.06	4.50

NOTE: Stable populations based on 1992 combined-sex life table for the United States (Berkeley Mortality Database).

Rescaling and economic behavior: Retirement trends

As life expectancy rises and health at older ages improves, it seems natural that the age at retirement should rise as well. For example, in assessing the effects of longer life, Kotlikoff (1981) makes two alternative assumptions: that the age at retirement rises in proportion to life expectancy at birth, or alternatively that it rises more than in proportion to life expectancy at birth, to keep the years of retirement at the end of life constant. In fact, however, in industrial countries age at retirement and older men's labor force participation rates have been dropping for more than a century, while life expectancy has risen by several decades (Costa 1998). In the United States in 1900, men retired in their early 70s, on average, compared with age 63 today (National Academy on an Aging Society 2000: 6). Labor supply at older ages has also declined sharply in developing countries (Durand 1977).

According to the US period life table for 1900, the ratio of the expected years lived after age 70 to those lived during ages 20 through 69 is 0.10. For each year spent working, 0.1 years would have been spent retired.[10] If retirement in 1995 still occurred at 70, mortality decline since 1900 would have raised this ratio from 0.10 to 0.23. Given that the mean retirement age actually has fallen to 63 for men, the ratio in 1995 of expected retirement years to expected work years has risen from 0.10 to 0.38, nearly quadrupling since 1900. In order to maintain the original ratio of 0.10 over the life cycle, the retirement age in 1995 would have to be moved to 78. If we were to allow for an earlier age at start of work in 1900, the results would be even more dramatic. While retirement age has stopped falling in the United States during the past decade, and has even modestly risen, the long-term trend has been strongly downward.

Ausubel and Grubler (1995) examined long-term trends, 1870 to 1987, in average hours worked over the life cycle for France, Germany, Great Britain, the United States, and Japan. They calculated disposable lifetime hours as $24 * 365e_{10}$, less $10 * 365e_{10}$ for physiological time (sleeping, eating, hygiene). For sexes combined in Great Britain from 1857 to 1981, they found that lifetime work hours declined from 124,000 to 69,000, while disposable nonwork hours increased from 118,000 to 287,000. Work as a share of total disposable hours (that is, work as a share of total lifetime nonphysiological hours above the age of 10) declined from 50 percent to 20 percent.[11]

Of course, much has happened over this period besides the increase in longevity. Growth in financial institutions and in public and private pensions has made it easier to provide for consumption in retirement. Income has increased and educational attainment has risen. Given these changes, it is perhaps not surprising that retirement age has fallen. Leisure is presumably a luxury good. We would expect its share of the life cycle budget to grow as income rises secularly. If life expectancy and health status had increased while hourly wages remained constant, then a decline in retirement age would seem unexpected. In this counterfactual case, we would probably expect a proportional increase in both work time and leisure time, to keep their marginal contributions to lifetime utility equal.

There is also abundant evidence that institutions and employers' practices have encouraged earlier departure from the labor force than individuals might have chosen otherwise. Discrimination against older workers used to be common. In the United States it has been addressed by a series of legislative acts of states going back to the 1930s and since the 1960s by federal law (Neumark 2001). The incentives for early retirement in employer-provided defined-benefit pensions are also important (see e.g., Lumsdaine and Wise 1994; Wise 1997). Strong incentives are also built into many defined-benefit public pensions, particularly when these are combined with incentives arising from tax policies, long-term unemployment benefits, and disability benefits. In a striking cross-national study of 11 OECD countries, Gruber and Wise (1997) found that in some countries the combined effect of such policies makes the net wage for continuing work after age 60 years drop close to zero or even turn negative, a very heavy "implicit tax." They found that this implicit tax accounts for most of the variation across countries in labor force participation rates at older ages.[12]

In sum, a combination of economic and institutional change, distorted incentives, and the behavioral response to these has caused the proportion of the life cycle devoted to work to shrink dramatically.

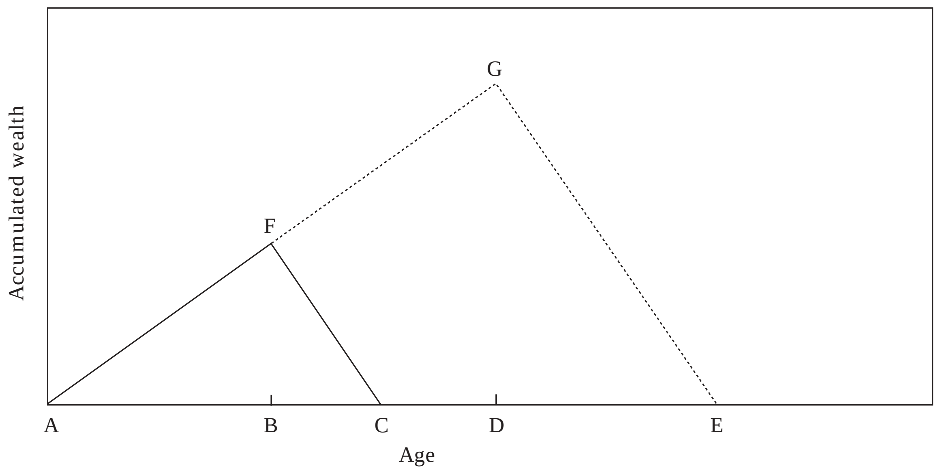
Rescaling and the economy

Consider now the effect of proportional rescaling on the economy, taking a doubling of life expectancy as a convenient, albeit implausible example. Under stock-constrained proportional rescaling, all flow variables would be only half as great, including wages, gross domestic product, and consumption and savings per unit time. Stock variables like capital would be unaffected at corresponding ages over the life cycle (that is, at ages representing the same proportion of life expectancy). The tax rate that would be required for the working-age population to support the retirement of the elderly through pay-as-you-go public pensions would remain the same at corresponding ages.

On reflection, however, this stock-constrained expansion of the life cycle is neither realistic nor appealing. When we hypothetically changed the measure of time from years to six-month units, in fact nothing changed, although all flow measures were halved. But if life expectancy were in fact to double, our unit of measure would nonetheless remain the year. In this case, we would not expect that output per year would be halved; nor wage rates, annual consumption, or savings. If people were to work twice as many years consistent with the proportionality assumption, then their lifetime earnings would be roughly twice as great (more or less, depending on returns to experience versus obsolescence of skills and knowledge), as would their lifetime consumption and savings. The cumulation of savings over twice as many years would generate assets at retirement that would be twice as large—as they should be, in order to finance a retirement that would be twice as long.

Figure 5 illustrates the implications for capital accumulation and the capital/labor ratio. The age at beginning work is denoted A; it will vary when longevity varies, but is treated as fixed for purposes of this figure. In a stationary population with one person born into each generation, the size of the labor force will initially be the distance AB. Accumulated wealth, held as capital, will grow linearly over the life cycle to amount F, and then be spent-down to fund retirement until death at age C, when it is exhausted.[13] The total stock of capital in the economy will be the area of the triangle AFC. The capital/labor ratio is this area divided by the number of workers, AB. Now suppose life expectancy doubles from AC to AE, and the age at retirement doubles from B to D. The new labor force is AD (continuing to

FIGURE 5 The nonproportional consequences of proportional rescaling on the aggregate economy: Earnings, savings, and the capital/labor ratio



NOTE: In the short life cycle, people begin work at age A and retire at age B having accumulated amount F to support their retirement until death at C. The capital/labor ratio is the area of triangle AFC divided by the number of laborers AB in a stationary population. In the doubled life cycle, people retire at D having accumulated amount G to support them in their longer retirement until death at E. The capital/labor ratio is the area of the triangle AGE divided by the number of workers in the stationary population, AD. If the generation size remains constant, there are twice as many workers with the doubled life cycle, since length AD is twice AB. However, there is four times as much capital, since G is twice F, and E is twice C. Therefore, the capital/labor ratio is twice as great. This assumes life cycle savings behavior, with constant earnings by age and zero interest.

assume one person per generation), and the new capital stock is the area of the triangle AGE. Since both the base and the height of AGE are twice as great as the corresponding dimensions of AFC, its area is four times as great. However, the labor force is only twice as great, so the new capital/labor ratio is twice the old.

The productivity of labor will be higher because of the increased capital per worker, so wages and gross domestic product will also rise, but by less than a factor of two owing to diminishing returns. The higher wages will further raise the capital per worker. The total effect might be to raise per capita income and wage rates by about 40 percent.[15] More capital per worker will mean a lower marginal productivity of capital, and lower profit rates and interest rates. Lower interest rates will in principle alter decisions about how to allocate consumption over the life cycle and savings decisions.

It also is not plausible to expect the acquisition of knowledge by an enrolled student to occur at only half the rate after a rescaling of the life cycle as it did before, as strict proportional rescaling would require. If the time in school doubles, we would also expect the stock of knowledge acquired to roughly double. Longer education and greater knowledge would also raise the productivity of labor and wages throughout the life cycle, interacting with the effects of capital that were just discussed. What would then happen to the rate of return to education, which provides the incentive for people to invest in learning? Longer life would increase the payback period, tending to raise the rate of return. However, returns would be decreased by the greater quantity of education. It is also unclear how the life cycle trajectory of labor earnings would be affected, given that accumulation of experience contends with obsolescence of knowledge and skills.

In sum, the proportional expansion of the life cycle does not make sense once we take into account some basic economic ideas. Life cycle expansion, even with proportionality, would imply increased human and physical capital per worker, lower profit rates and interest rates, higher wages and per capita incomes, and altered returns to education and altered life cycle earning trajectories.

How might rising per capita incomes affect people's choices? Often economists assume that the preference functions governing choices among goods and activities are homothetic, meaning that as incomes rise, the utility tradeoffs (marginal rates of substitution) between items do not change if goods are consumed in the same proportion. Such an assumption here would preserve a proportional expansion of some aspects of the life cycle, despite rising incomes. When we think about saving behavior—trading off consumption today against consumption in old age, for example—this assumption may be defensible. However, it is more questionable in the context of the tradeoff between consumption and leisure, which will influence hours worked per day as well as the decision about when to retire.

Conclusions

We have explored the consequences of longer life for the timing of life cycle events between birth and death. We have used proportional rescaling as a baseline against which to compare the actual past and the potential future. Proportionality is not inevitable. In many cases, it is not even likely. In almost no case is the timing of life cycle events changing at exactly the same pace as longevity itself is increasing. Still, proportional rescaling provides a starting point, a simple framework, from which to view the largely unexplored consequences of increasing longevity for the timing of different segments of life. We do not suggest that all the changes we considered are directly or indirectly caused by increased longevity. In some cases there are plausible links, but in many cases the causes of change are not in any obvious way connected to mortality change.

In order to get the broadest picture, it is useful to set aside issues of the exact pace at which changes are occurring and to ask simply which life cycle stages are changing in a direction consistent with proportionality. As we live longer, we are indeed spending more time in school, staying single longer, delaying reproduction, delaying entry into the work force, and staying healthy longer. On the other hand, childhood at least as it is socially defined is not lengthening, and working life has shrunk. Biologically, human growth, maturity, and menopause have remained nearly fixed, even as life has been extended.

The barriers to proportional rescaling are behavioral, institutional, and biological. From a behavioral point of view, people have chosen to allocate increasing shares of life to leisure. As we have seen over the last century, longer and wealthier life has been accompanied by proportionately more years spent in leisure, not fewer. Although population aging may not allow the historic trend toward earlier retirement to continue, it is likely that leisure time, perhaps spent not only in retirement but also before entry into the labor force and perhaps during the working years, will increase at a faster than proportional rate with increased longevity.

Institutions also form barriers to proportional rescaling. For example, incentives for early retirement have grown with the generosity of pension programs in recent decades, amplifying the behavioral effects. Similarly, age-graded eligibility, whether it be for insurance, military service, or tax treatment, makes the timing of life cycle stages less elastic than it might otherwise be. Institutions may ultimately adapt to behavioral preferences, but they will do so slowly.

Finally, biological barriers to proportional rescaling appear. Because increased longevity is not a result of evolutionary forces that fundamentally change human biology, changes in mortality rates are not accompanied by changes in the timing of human growth, the length of time infants are physically dependent on their parents, sexual maturity, or menopause. Human aging may be slowing, but this is not yet influencing the timing of human development. However, biological constraints do not yet block proportional increases, at least in terms of weak proportionality, in the timing of reproduction. The mean age of childbearing could rise considerably before it reached current biological limits.

This chapter only touched on the wide range of issues that increasing longevity might imply for the reorganization of human life. Among the many worthwhile topics to pursue are the consequences of rescaling for a number of life cycle models. Mincer's (1974) formulation of human capital accumulation might be explored, looking specifically at the effect of proportional increases in education on entry into the labor force and on the age profiles of earnings. Under what conditions would the earnings peak itself move proportionally? What would happen to lifetime income? What would be the consequences for the opportunity costs of childbearing? A second area for research is the aggregate economic consequences of longer life. We have seen that even under proportionality, the consequences of longer life are not economically neutral, since human and physical capital per person would grow with the square of longevity. Further investigation of the equilibria implied by both proportional rescaling and different scenarios of non-proportional change would be revealing.

Another issue to consider is the plausibility of repetition as an alternative to elongation of life cycle states. To some extent, the increase in remarriage and in formation of "second" families suggests that many aspects of life may not be so constrained as we have suggested from our emphasis on stock constraints. Several distinct periods of schooling could be an alternative to simply adding years of schooling at the beginning of life. One could imagine that several careers, several families, and several hometowns could emerge with increased longevity. The viability of the repetitive life cycle as opposed to the elongated life cycle will depend on economic factors such as the depreciation rate of human capital with time, the earnings trajectory and value of experience in a particular career, and changing perceptions of social issues that make the unity of the life course a defining element of human identity. Perhaps the repeated life cycle may be psychologically unappealing, if the value of social networks of family, neighbors, and colleagues is so strong as to make full replacement impossible.

Finally, rescaling confronts measures of time that are external to the human life cycle. For many animals and plants, the length of the seasons is a fundamental unit of time, an underlying metronome that does not allow continuous rescaling. For humans, underlying pacemakers of life, external to human behavior, are some of the main obstacles to simple proportional change. Human skills degrade at some rate with nonuse, we learn at some rate, children grow up at some rate, social bonds are created and dissolved at some rate, technology changes at some rate, and so forth. To a large extent, the effect of longer life on the rescaling and reorganization of the life cycle will be determined by what happens to people's valuation of time in a general sense. The economic value of time in terms of productivity and earnings is one aspect of this. Another aspect is the various units of time: the workweek, the school year, and other rhythms of human life.

Notes

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1 As an example, consider the life table survival function, $l(x)$, and the density of deaths at age x, $d(x)$. Consider a proportional rescaling such that new age y equals x/c. If the new functions are l^* and d^*, then for c=2 we would have $l^*(100) = l(50)$. That is, under the new mortality regime, the proportion of people now survive to 100 that used to survive to 50. The density of deaths is given by $d(x) = -\mathrm{d}l(x)/\mathrm{d}x$ (where the d for derivative should not be confused with the d for deaths). It follows that $d^*(x) = (1/c)d(x/c)$. That is, not only is the $d(x)$ curve stretched out, but its level is also reduced by the factor $1/c$ at each x. $d(x)$ is stock constrained, because it must integrate across all ages to 1.0 or to the radix of the life table.

2 Another way to assess proportional stretching is to plot the old and new survival curves against the logarithm of age. The same horizontal displacement will then correspond to a proportionate increase in age from any starting point. Under strong proportionality, the horizontal distance between the two survival curves should be a constant, in our example equal to log(2). If the two curves being compared are rates, expressed per unit time, then the new curve should first be multiplied by c before plotting against the logarithm of age (see note 1 above).

3 Formally, for any s, $m(x,t) = m(x+\mathrm{r}\,s/\mathrm{q},t+s)$.

4 The probability of surviving to age 50 in the 1995 period US life table for sexes combined was .925, and it is projected to be .965 in 2080.

5 Costa (2000) reports that from the early twentieth century to the 1990s, the average rate of functional disability for men aged 50 to 74 declined at 0.6 percent per year. Crimmins et al. (1997) have found similar rates of decline for recent decades, while Manton et al. (1997) and Freedman and Martin (1999) find considerably more rapid rates of decline, and Manton and Gu (2001) report accelerating rates of decline in chronic disability since 1982.

6 Analyses of data from the Social Security disability insurance program (DI) tell a different story, but those disability rates are dominated by behavioral responses to the incentives of the program and appear to be less relevant than direct measures of illness or functional status.

7 Couple formation, particularly in Sweden, is poorly measured by marriage alone, since cohabitation is so common. Levels of cohabitation are lower in the United States, and lower still in Japan.

8 For example, both Sweden and the United States lowered their voting ages from 21 to 18 during the 1960s and 1970s.

9 The baby boom years following World War II were accompanied by a dip in the mean age of childbearing.

10 Note that it is incorrect to base a calculation of this sort on the change in life expectancy at age 65. The probability of surviving from age 20 to age 65 increased from 0.52 in 1900 to 0.82 in 1995, for example. The correct calculation is based on T65/(T20–T65), which is the ratio of years lived after age 65 to those lived during ages 20–64 over the individual life cycle. These calculations do not take into account the distribution around the mean age of retirement.

11 Unfortunately, Ausubel and Grubler worked with life expectancy and not survival distributions, an approach that exaggerates the size of these proportional declines in work time.

12 The public pension programs in the United States and Japan stand out has having relatively little incentive for early retirement. In the US, at least, many employer-provided plans do have strong incentives, however.

13 Consumption in old age may also be funded in part by transfers from workers, as with pay-as-you-go public pension systems. The argument in this paragraph applies to the portion of consumption in retirement that is funded through private savings or employer-provided pensions. For simplicity the calculations ignore the return to investments in capital.

14 Under stock-constrained proportional stretching, the flow of births would actually be only half as great as before, so there would be only one-half person per generation. The total labor force size would be unchanged, but there would be twice as much capital, since the average worker holds twice as much capital as can be seen from Figure 5. All that really matters is the ratio of capital to labor, so the size of generations in the stationary population is irrelevant.

15 Suppose that per capita income is proportional to the capital/labor ratio raised to the 1/3 power, a standard assumption, and that the new capital/labor ratio equals the old times 2 times the ratio of new to old per capita income. Solving, we find that the ratio of per capita incomes equals the square root of 2, or about a 40 percent increase.

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