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ON THE LIMITS OF CHRONOLOGICAL AGE

Rainer Kotschy
David E. Bloom
Andrew J. Scott

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ABSTRACT

Analysis of population aging is typically framed in terms of chronological age. However, chronological age itself is not necessarily deeply informative about the aging process. This paper reviews literature and conducts empirical analyses aimed at investigating whether chronological age is a reliable proxy for physiological functioning when used in models of economic behavior and outcomes. We show that chronological age is an unreliable proxy for physiological functioning due to appreciable differences in how aging unfolds across people, health domains, and over time. We further demonstrate that chronological age either fails to predict economic variables when used in lieu of physiological functioning, or that it predicts additional effects on economic behavior and outcomes that are largely unrelated to physiological aging. Continued reliance on chronological age as a proxy for physiological functioning might impede the ability of societies to fully harness the benefits of increasing longevity.

Rainer Kotschy
National Bureau of Economic Research
1050 Massachusetts Ave
Cambridge, MA 02138
and Harvard T.H. Chan School of Public Health
rkotschy@hsph.harvard.edu

David E. Bloom
Harvard T.H. Chan School of Public Health
Department of Global Health and Population
665 Huntington Ave.
Building 1, Suite 1202
Boston, MA 02115
and IZA
and also NBER
dbloom@hsph.harvard.edu

Andrew J. Scott
Department of Economics
London Business School
Sussex Place,
London NW1 4SA, UK
ascott@london.edu

1 Introduction

Because of declining fertility and rising life expectancy, populations worldwide are aging. The force of aging and analysis of its consequences are typically framed in chronological terms. For instance, the median age of Japan's population was 21.2 in 1950 and 48.0 in 2020 and is expected to reach 53.6 by 2050, while the population share aged 65 and older has increased from 4.9 percent in 1950 to 29.6 percent in 2020 and is projected to rise to 37.5 percent by 2050 (United Nations 2022).

Chronological age has practical advantages as a measure of aging: it is easy to understand, easy to measure, and commonly defined across people and over time. Nevertheless, chronological age itself is not necessarily deeply informative about aging and may only inaccurately reflects a person's ability and competence (Edwards 1950). Its value for research and policy depends on its usefulness in tracking the patterns and trends in aging that matter for the objects of inquiry. For instance, healthcare costs might drastically increase in an aging population if health progressively deteriorates with chronological age (Schneider and Guralnik 1990). Here physiological decline is the object of interest and chronological aging serves as a proxy for it. However, research suggests chronological age insufficiently approximates the complex dynamics of physiological decline and thus overstates age-induced growth of the healthcare sector (e.g., Zweifel et al. 1999; De Meijer et al. 2013).

Maybe paradoxically, chronological aging is the most widely applied concept of population aging, even though it contains limited information about the aging process and is silent about adaptive policies in response to population aging (see, e.g., Scott 2021). Indeed, monitoring success of the United Nations' Decade of Healthy Ageing necessitates non-chronological approaches to the measurement of population aging (Lowsky et al. 2014; Bautmans et al. 2022).

This inconsistency between the use of chronological age and its informational content raises two questions. First, how informative is chronological age in accounting for people's physiological aging? And second, how does chronological age compare in predicting economic behavior and outcomes to alternative function-based measures based on physiological aging?

Here we investigate chronological age with respect to the inferences it supports about people's physiological functioning and their economic behavior and outcomes when used as a substitute for the latter. By physiological functioning we mean the physical and mental capabilities that reflect a person's capacities, physiological reserves, and resilience against disease and that tend to decline through the gradual accumulation of molecular and cellular damage over time (cf. WHO 2015).

The use of chronological age in policy and research to approximate physiological functioning and its decline through aging implicitly assumes that chronological age can serve as a sufficient statistic that captures the relevant patterns and trends in physiological functioning. This assumption prompts at least three concerns. First, people of the same age differ appreciably in physiological functioning (heterogeneity). Second, the rate at which people age and thus the age patterns of physiological functioning can change over time (malleability). And third, the age patterns of physiological functioning differ across health domains and trend differentially over time (multidimensionality). If these concerns are substantive, reliance on chronological age to examine the consequences of population aging will produce an incomplete if not misleading picture.

To assess the extent of these limitations of chronological age in accounting for physiological functioning and its economic effects we proceed as follows. We first describe how chronological age emerged as an indicator of old age and physiological decline in modern times and review economic issues in which aging plays a substantive role. In general, chronological age is used either as a proxy for physiological functioning and its decline or as a broader measure of life-cycle aspects, such as experience and current life stage, which are not exclusively related to aging. This dual use indicates that chronological age and physiological functioning can contain different informational content, creating ambiguity about how to interpret the effects of chronological age on economic outcomes.

We then summarize several measures literature uses to capture physiological functioning. Out of these measures, we focus on a frailty index—a widely applied composite indicator of health deficits—to analyze the age patterns of physiological functioning in longitudinal data from the U.S. Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing. Our assessment shows that chronological age accounts for less than 10 percent of the variation in physiological functioning across people and over time. Moreover, we demonstrate that the age patterns of physiological functioning differ appreciably across populations, birth cohorts, and health domains, documenting heterogeneity, malleability, and multidimensionality of physiological functioning.

These results corroborate the concern that chronological age is an unreliable proxy for physiological functioning. To examine the extent of this concern in economic research, we conduct correlational regression analysis testing the use of chronological age and physiological functioning in predicting labor supply and productivity, productive nonmarket activities, life satisfaction, and medical outcomes. Our results indicate that chronological age does not predict economic behavior and outcomes when used in lieu of physiological functioning, or that it predicts an independent effect of chronological age on economic behavior and outcomes in addition to physiological functioning. Our findings suggest that reliance on chronological age as an indicator of physiological functioning and aging might impede society in fully realizing the benefits of increased longevity.

2 Age, Aging, and the Economy

Changing patterns of economic activity with age have always been a feature of human society. However, what we do at different ages varies across people, how age is interpreted has changed over time, and what particular dimension of aging is relevant depends on the issue of interest.

2.1 The Emergence of Chronological Age

Distinct notions of age and life stages already existed in pre-modern societies and social divisions of human society along them were common (Eisenstadt 1956). These distinctions played an important role in determining how people were treated, how they should behave, and the authority they exercised (see Thomas 1976 for an account of 16th- to 17th-century England).

As few people were numerate, life stages were defined by a mix of physiological evidence (e.g., puberty) and social convention (e.g., when one mastered a trade or married) rather than by chronological age (Thomas 1976; Roebuck 1979). However, this approach posed problems for defining who was old. For instance, in 1601 England introduced the Elizabethan Poor Laws to provide for the poor and old, where the latter were defined as those incapable of supporting themselves, such that old age was "more a question of function, or lack of it, than a question of calendar years" (Roebuck 1979, p. 417).

The concept of chronological age supplanted this functional approach and began to form the basis for an increasing number of regulations in the 18th century in the United Kingdom and in the 19th century in the United States (Thomas 1976; Chudacoff 1989). According to Thomas and Chudacoff, rising numeracy and literacy, better record keeping, the industrial revolution, and the demands of an expanding bureaucracy seeking consistency contributed to this shift.

With the introduction of public pension systems, bureaucracies codified chronological age thresholds to determine eligibility for old-age security. In 1889, Germany launched the world's first modern old-age pension system, stipulating a retirement age of 70 (Mierzejewski 2016). Denmark, the United Kingdom, and France among other countries followed and introduced their own pension systems with retirement ages between 60 and 70 (Thane 2006). From a bureaucratic point of view, the use of chronological age was a distinct improvement because it replaced costly and subjective tests of functional ability with certain and impartial classification practices (Treas 2009).

Macroeconomic and social considerations drove governments to choose specific retirement ages. Concerns about fiscal solvency motivated higher age thresholds (Mierzejewski 2016), whereas the belief that retirement would ease contemporary problems of high unemployment among older workers motivated lower age thresholds (Costa 1998). In addition, retirement ages had to broadly conform to existing social conventions regarding the advent of old age, which had most frequently been identified as occurring during the seventh decade of life (Thane 2006).

As governments relied increasingly on chronological age, researchers designed new measures of population aging (for a review, see Sanderson and Scherbov 2019). Ballod (1913) introduced the "coefficients of burden," dividing the number of children (0–14) and elderly (70 and older) by the number of prime-age workers (20–59) who had to support them, assuming younger and older workers (15–19 and 60–69) would provide for themselves. Notestein et al. (1944) simplified these coefficients to develop the well-known total dependency and old-age dependency ratios. Günther

(1931) and Cutler et al. (1990) extended these concepts to develop the economic support ratio, which accounts for the fact that people can produce and consume at the same chronological age.

While chronological definitions of old age may have originally been based on past social conventions, they have themselves become definitions of old age over time and now frequently define social convention and our understanding of population aging.

2.2 Chronological Age and Physiological Functioning in Economic Literature

Chronological age has become a shorthand way of summarizing aging issues, but a review of the economic literature reveals it is rarely the variable of interest. At the heart of much economic analysis is the theory of consumer choice, according to which individuals have an earning span during which they work and save for the future and a retirement span during which they live off their savings. Since early contributions (e.g., Modigliani and Brumberg 1954; Samuelson 1958) this theory has been greatly enriched to capture a wider range of aging-related issues. A non-exhaustive list of topics in which age plays a prominent role includes consumption, time allocation, wellbeing, preferences, labor supply and retirement, educational investment, health, saving, productivity, innovation, entrepreneurship, and macroeconomic performance. Across these topics the relative importance of chronological age and physiological functioning varies appreciably.

Consumption, Time Allocation, and Wellbeing. Consumption behavior and time allocation change through life. Expenditure on food, for instance, tends to drop at the time of retirement, which appears inconsistent with the notion of consumption smoothing and raises concerns about liquidity problems during retirement (Hamermesh 1984; Banks et al. 1998). Accounting for shifts in people's time allocation toward home production (including shopping for groceries and preparing meals) and work-related expenses after retirement can explain the drop in consumption (Aguiar and Hurst 2005; Battistin et al. 2009). Labor force exit due to health shocks and saving for future medical expenditures also lower consumption at older ages (Hurst 2008; Blundell et al. 2024).

More generally, time spent on nonmarket activities increases with chronological age and has risen in recent decades (Aguiar and Hurst 2007). These activities matter for the economy: Bloom et al. (2020) calculate that the population 65 and older contributes about 2–3 percent to gross domestic product in the United States and Europe every year through productive nonmarket activities. For more information on time use, see Hamermesh (2019) and Ferranna et al. (2023).

People's wellbeing is also systematically related to chronological age. Data from the United States and Europe show wellbeing decreases with age until it reaches a trough in midlife and then increases (Blanchflower and Oswald 2008; Blanchflower and Graham 2023). However, this pattern is controversial in that it holds mainly in rich English-speaking countries, whereas wellbeing tends to fall with chronological age in other countries (Deaton 2008). Moreover, evidence of U-shaped happiness patterns tends to occur after conditioning for variables that are age-related such as income and health, which may remove relevant variation (Deaton 2018). This debate is an example of ambiguity in interpreting the effects of age and aging. Do age patterns in wellbeing reflect different circumstances due to the passage of time, as captured by chronological age, or do they reflect changes in people's capacities, as captured by physiological functioning?

Preferences. Preferences tend to vary with chronological age and health (for a survey, see Dohmen et al. 2023). Using the Global Preferences Survey, Falk et al. (2018) document patterns in time, risk, and social preferences with respect to age, gender, and cognitive ability. Heterogeneity in people's physiological functioning can explain some of these patterns. Dohmen et al. (2011) demonstrate that willingness to take risks tends to increase with height (a proxy for childhood health) and patience tends to rise with longevity (Becker and Mulligan 1997; Falk et al. 2019). Furthermore, Banks et al. (2020) find that health shocks and other life events that occur at older ages account for half the decrease in willingness to take risks observed at these ages. Finally, evidence from the World Values Survey shows that support for democracy increases with age but declines with expected proximity to death (Lechler and Sunde 2019; Kotschy and Sunde 2022).

Labor Supply and Retirement. Many factors including physiological functioning influence people's labor supply and retirement (Blundell et al. 2016). To deal with the complexity in analyzing these decisions, research uses structural models in which individual health and survival probabilities, which depend on chronological age, account for physiological functioning (e.g., French and Jones 2011; Kuhn et al. 2015). This literature finds that health deterioration plays an important role in employment over the life cycle: for instance, labor force participation and hours worked at a given chronological age in the United States differ appreciably between men who assess themselves as in good health and men who do not (French 2005, p. 408). Nevertheless, literature shows that health deterioration is not the primary source of variation in retirement across countries and over time (French and Jones 2017). Diminishing health explains up to 15 percent of the decline in employment between ages 50 and 70 in the United States and England (Blundell et al. 2023).

The codification of age thresholds in social security laws that came with the introduction of public pension programs directly links chronological age and retirement behavior. Many pension programs stipulate earliest and latest eligibility ages bracketing a "normal retirement age," thereby creating financial incentives that induce workers to prepone or postpone labor force exit (e.g., Gruber and Wise 1999; Börsch-Supan et al. 2016; Fetter and Lockwood 2018). Establishing retirement ages in the law further creates norms that cause a bunching of labor force exits around those retirement ages (Behaghel and Blau 2012; Seibold 2021).

Against this backdrop, literature investigates labor market outcomes of older workers. Labor force participation of older people has increased in many high-income countries on the strength of a healthier and better trained workforce; rising female labor force participation; and reforms of labor market regulations, pension systems, and health insurance (D'Albis 2023). Despite this increase, the probability of older workers joining a new employer is low compared with that of other age groups and has fallen in the United States over the past 25 years (Allen 2023). One explanation for this finding is that older workers prefer flexible work and are thus more likely to be self-employed (Abraham et al. 2021). Evidence suggests they especially value work that is flexible in hours, is not physically demanding, and offers autonomy (Ameriks et al. 2020; Maestas et al. 2023b). An alternative explanation for this finding is that older workers tend to face age discrimination in hiring, as experimental evidence from the United States indicates (Neumark et al. 2019).

Education, Health, and Saving. The rate of return on education increases with (working) lifespan, which depends on mortality, morbidity, and the statutory retirement age (Mincer 1958; Becker 1962). Theoretical work building on those insights shows that increases in life expectancy raise the return on schooling and lifetime labor incomes but has indeterminate effects on life-cycle labor supply (Ben-Porath 1967; Cervellati and Sunde 2013; Sánchez-Romero et al. 2016). Empirical evidence confirms these predictions by demonstrating that increases in U.S. adult life expectancy through 1960–2000 promoted college enrollment (Hansen and Strulik 2017), boosted the growth of income per person and exerted nonlinear effects on age-specific labor supply (Kotschy 2021), and contributed to rising income inequality (Kotschy 2022). Extensive literature also emphasizes the beneficial effects of childhood health for economic outcomes (for a survey, see Almond et al. 2018).

According to the standard life-cycle model, saving inter alia depends on income and the expected length of life. Consistent with this prediction, rich and healthy people who tend to live longer also save more at a given chronological age than their poorer and less healthy counterparts (De Nardi et al. 2009). Moreover, uncertain longevity and the risk of requiring expensive medical care also motivate saving among higher-income elderly (De Nardi et al. 2010). In addition, retirement incentives set by age thresholds in social security laws explain the association between longevity and saving: people save more for a longer expected old-age period because retirement ages usually do not automatically increase with life expectancy (Bloom et al. 2007).

Productivity and Innovation. A feature of life-cycle models is that earnings vary with age. Workers tend to be more productive in a job when they have received more formal training and are more experienced (Mincer 1958, 1974). Productivity further depends on workers' physical and cognitive capacities, many of which peak early in life and decline thereafter (e.g., Börsch-Supan and Weis 2023). These factors suggest a flattening-out or even hump-shaped age pattern in productivity, which has empirical support especially at the macroeconomic level (Lindh and Malmberg 1999; Heckman et al. 2006; Feyrer 2007; Kotschy and Sunde 2018). However, microeconomic evidence indicates that productivity need not decline with age. Data from car manufacturing show that the beneficial effects of growing experience can be large enough to offset the adverse effects of deteriorating capacities, such that individual productivity does not decline at least until age 60 (Börsch-Supan and Weiss 2016). Moreover, age-specific productivity in the service sector varies appreciably across tasks, with flat or upward-sloping patterns in nonroutine tasks and downward-sloping patterns in basic routine tasks (Börsch-Supan et al. 2021).

Age patterns in productivity are context-specific and may thus change over time. For instance, the average age at which Nobel laureates and great inventors contributed their most notable work increased by about 10 years through the 20th century (Jones 2010; Jones and Weinberg 2011). Cognitive performance also increased for younger and older ages of a wider population, as evidenced by correct moves in chess games across age cohorts (Strittmatter et al. 2020). The ongoing trends toward more age-friendly jobs and automation in the economy might further fortify productivity of older workers in the future (Acemoglu et al. 2022; Acemoglu and Restrepo 2022).

Macroeconomic Performance. Chronological age plays a prominent role in macroeconomic analysis. Literature documents that changes in population age structure create the opportunity for a demographic dividend on the strength of increasing labor input; savings; investment in health, education, and innovation (Bloom and Williamson 1998; Bloom et al. 2003). The dividend is higher when working-age cohorts have high levels of education (Kotschy et al. 2020). Recent literature investigates the extent to which population dynamics might slow economic growth in the future. Based on global data, Kotschy and Bloom (2023) document that foreseeable changes in population age structure are likely to act as a demographic drag on economic growth. Using a theoretical model calibrated to the United States, Cooley and Henriksen (2018) predict that population aging will decrease labor supply and decelerate growth of output and total factor productivity. Consistent with these predictions, Maestas et al. (2023a) find that an increase in the 60 and older population share might lower output per capita through slower growth of employment and labor productivity. However, the chronological aging indicators employed in these studies likely overstate the economic slowdown associated with population aging because they do not account for the fact that improvements in physiological functioning among older people can expand labor potential and cushion the demographic drag (Kotschy and Bloom 2023).

Further research relates demographic trends to other macroeconomic outcomes. Population aging and shrinking might, for instance, slow innovation (Aksoy et al. 2019; Jones 2022), lower firm entry and increase employment concentration in large firms (Hopenhayn et al. 2022; Karahan et al. 2024), power inflation due to dissaving and labor shortages (Lindh and Malmberg 2000; Goodhart and Pradhan 2020), and limit the scope for monetary policy by pushing the real interest rate below the zero lower bound during recessions (Eggertsson et al. 2019).

Policy Implications of Population Aging. In policy debates, the challenges associated with population aging are typically framed in terms of chronological measures of aging. For instance, continual increases in old-age ratios raise concerns about the fiscal integrity of pension, healthcare, and long-term care programs (Rouzet et al. 2019). The standard policy response is to recommend longer working lives, in terms of both raising employment among those who are pre-retirement age and strengthening working lives beyond the statutory retirement ages (OECD 2019, 2023).

A concern with such policy recommendations is that chronological age might not be a good predictor of age-related labor market potential. While data on occupation-specific functional requirements from the United States suggest many people maintain the functional ability to work well into their late 60s (Berger et al. 2022), employment rates decline from 50 onward—especially among those with low levels of education (Truesdale et al. 2022).

3 Chronological Age and Physiological Functioning

As our review shows, aging issues affect a broad range of economic research and policy-making. Chronological age appears in many of the reviewed settings either as a proxy for physiological functioning and its decline or as an indicator of age-related and time-related factors such as experience, life stage, and access to social security benefits. This dual role raises two conceptual concerns. First, the use of chronological age as an indicator of physiological functioning requires a sufficiently strong and precise correspondence between age and functioning. Second, the use of chronological age is not limited to physiological functioning but includes other dimensions related to the economic life cycle, complicating the interpretation of the dimensions of aging that are most important economically. Therefore, researchers have searched for alternative indicators of physiological functioning.

3.1 Physiological Functioning

Given the importance of physiological functioning in determining the economic impact of aging, several indicators have been proposed to measure (domains of) physiological functioning.

McFarland (1943) first introduced the notion of functional age into scientific literature, studying the capabilities of older workers to perform their job. While this particular approach was criticized as being overly dependent on the specific nature of a job, the broad notion of emphasizing functioning, whether biological or behavioral, was seen as key in providing deeper insights into aging than chronological age (Salthouse 1986). In biological terms, "[a]ging is characterized by a progressive loss of physiological integrity, leading to impaired function and increased vulnerability to death" (López-Otín et al. 2013, p. 1994).

The link between physiological integrity and death combined with the widespread availability of life tables across counties and over time makes mortality schedules and life expectancy convenient measures of physiological functioning and aging. Through the 20th century, many high-income countries experienced unprecedented declines in infectious and cardiovascular disease mortality rates that lifted life expectancy at birth by around 30 years (Cutler et al. 2006), with gains in life expectancy now being increasingly realized late in life (Eggleston and Fuchs 2012).

Given these improvements in life expectancy and assuming they at least partly reflect better physiological functioning, fixed chronological definitions of "old age" appear misleading. Therefore, Ryder (1975) proposed redefining old age using expected years left to live rather than years already lived. Sanderson and Scherbov (2005, 2007, 2010) generalized this approach, introducing a prospective old-age ratio, which uses a flexible age threshold equal to the age at which remaining life expectancy is 15 years. They chose this value to match life expectancy at age 65 in low-mortality countries around 1970 (Sanderson et al. 2017). Adjusting for increased life expectancy in this manner leads to different predictions of the pace at which populations age compared to the conventional approach that defines the start of old age at 65: population aging is slower if a society's remaining life expectancy is more than 15 years at age 65, and faster if it is less (Sanderson and Scherbov 2019, pp. 66–72). Milligan and Wise (2015) use a related approach based on mortality as a measure of health and physiological functioning to assess people's capacity to work at older ages in 12 Organisation for Economic Co-operation and Development countries. Milligan and Wise find that U.S. men aged 55–69 could have worked nearly four more years in that age range in 2007 than in 1977 due to lower mortality rates.

The advantage of mortality measures of physiological aging is their availability and consistency across countries and over time. However, mortality is the end point of life and how health evolves before then is also important. Thus, a question is whether people live longer in good health, in line with the concept of compression of morbidity (Fries 1980). Researchers apply various indicators based on disease and disability to examine morbidity and measure population aging, including disability-adjusted life years (Murray 1994); healthy (disability-free) life expectancy (Crimmins et al. 2009; Jagger and Robine 2011); disease burden (Vos et al. 2020); healthy working life expectancy (Lynch et al. 2022); and health-adjusted dependency ratios (Skirbekk et al. 2022). Yet, the debate on whether there is compression of morbidity remains ongoing (e.g., Cutler et al. 2014; Crimmins et al. 2021).

Alongside these primarily health-based approaches to defining physiological functioning, there are also behavior-based approaches. For instance, Katz (1983) proposes to assess people's self-maintenance ability in terms of performing necessary activities of daily living (such as dressing oneself and taking medication). Counting limitations in those activities in international data, Sudharsanan and Bloom (2018) find evidence of improvements in physiological functioning by age over time. Fried et al. (2001) instead characterize people as frail based on unintentional weight loss, self-reported exhaustion, weakness, slow walking speed, and low physical activity and show that this classification predicts falls, disability, hospitalization, and mortality.

Mitnitski et al. (2001) developed another approach to measuring physiological functioning by constructing a frailty index that records how many aging-related health conditions a person has. This index is computed as the unweighted fraction of health deficits out of a long list of conditions, which ranges from mild to near-lethal health deficits and includes health-based and behavior-based indicators (for a survey, see Strulik 2023). The frailty index is conceptualized as a macroscopic variable describing the overall age-associated vulnerability of a person rather than any specific functional deficiency (Rockwood and Mitnitski 2007). It has been widely used to examine patterns and trends in physiological aging across people, birth cohorts, and over time (e.g., Abeliansky and Strulik 2018; Blodgett et al. 2021; Hosseini et al. 2022; Old and Scott 2023).

The aforementioned approaches center on the loss of physiological functioning through disease, disability, and death. Another approach is to measure physiological functioning biologically. For instance, Levine and Crimmins (2018) find evidence of improvements in how people age in U.S. data, using biomarkers of metabolic, cardiovascular, inflammatory, kidney, liver, and lung functioning. Alternatively, genetic literature developed so-called epigenetic clocks that calculate tissue-specific biological ages based on metabolic changes to a person's DNA (Horvath and Raj 2018), potentially offering an accurate measurement of biological age.

Finally, another approach motivated by the World Health Organization's concept of healthy aging is to define physiological functioning by a person's intrinsic capacity, which reflects the composite of physical and mental capacities of that person (WHO 2015). Beard et al. (2019) and Beard et al. (2022) operationalize intrinsic capacity statistically, producing a low-dimensional measure of physiological aging based on biomarkers and self-reported indicators.

3.2 The Link between Chronological Age and Physiological Functioning

The use of chronological age as an indicator of population aging assumes that chronological age is essentially a sufficient statistic for multiple aspects of aging and captures relevant information about physiological functioning. However, this assumption raises at least three concerns.

First, people of the same age tend to differ in physiological functioning because of heterogeneity in how they age. For instance, life expectancy of U.S males aged 25 in 2006 was 9 years higher among college graduates than among those without a high school degree (National Center for Health

Statistics 2012, p. 37). The dispersion of physiological functioning also varies across countries. In 2016, the gap in life expectancy at age 25 between people with high and low education was only about 2 years in Japan but 15 years in the Republic of Korea (Lübker and Murtin 2023, pp. 2–3).

Second, the rate at which people age is malleable and changes over time. For instance, higher living standards, medical advances, and public health measures that support healthier lifestyles and living environments might permanently slow the pace of physiological aging. Indeed, the Global Burden of Disease Study finds that global health, as measured by age-standardized disability-adjusted life years, has continually improved over the period 1990–2019 (Vos et al. 2020). Notably, malleability of the physiological aging process can operate in both directions, such that physiological functioning might also deteriorate across birth cohorts, for instance, due to a rising prevalence of obesity (Flegal et al. 2016) and drug-related deaths (Case and Deaton 2017). Because the rate at which people age might change, inferring the prospective economic consequences of population aging with chronological measures of age is challenging.

Third, the age patterns of physiological functioning are multidimensional and differ across health domains, which tend to include physical, cognitive, psychological, sensory, and social components (see, e.g., Ware and Sherbourne 1992). As people age, their physiological functioning might change in some domains but not in others (Beard et al. 2019; Old and Scott 2023). Chronological age is too broad and inflexible to capture these differential trends.

To assess the extent of these concerns regarding the use of chronological age, we use longitudinal data from the United States and England. Specifically, we compare the distributional characteristics of physiological functioning conditional on chronological age within and across the United States and England and across birth cohorts and different domains of physiological functioning.

3.3 Measurement of Physiological Functioning

For our analysis, we construct measures of physiological functioning using data from Waves 3–15 of the Health and Retirement Study (HRS 2023b) and Waves 1–9 of the English Longitudinal Study of Ageing (Banks et al. 2021). We confine the age range of respondents in our sample to 50–90 and exclude older people for whom data availability and selection are concerns. Table A.1 in the Supplemental Appendix reports descriptive statistics.

Our main measure for physiological functioning is the frailty index suggested by Mitnitski et al. (2001), which records the fraction of health deficits a person has out of a list of aging-related health conditions and which is prognostic of mortality (see Strulik 2023). We rely on the frailty index because we can easily construct it for different populations, birth cohorts, and time periods with existing data that also contain the information on economic behavior and outcomes needed for answering our research question. In robustness analyses, we show that our key findings do not hinge on the specific measure of physiological functioning chosen. We construct our frailty index using the same 42 health deficits across countries and waves, which cover the areas of mobility, activities of daily living, instrumental activities of daily living, depression, age-related diseases, cognition, and body mass (see Table A.2 for a list of the survey items).

The frailty index tends to be insensitive with respect to the exact list of health conditions included so long as i) the number of health deficits is sufficient (at least 30–40), ii) the conditions reflect health deficits rather than age-related attributes such as gray hair, iii) health deficit prevalence tends to increase with chronological age, iv) health deficits do not saturate too early (excluding conditions such as age-related near vision, which are almost universal in older people), v) the health conditions cover a range of functional domains, and vi) the health conditions in the index are the same from one period to the next when used in longitudinal analysis (Searle et al. 2008). The intuition for this insensitivity is that health deficits fulfilling these criteria tend to be correlated with one another, such that they show similar patterns so long as enough health conditions are included in the frailty index (Strulik 2023). If a particular health condition is omitted from the frailty index, this condition's effect on the outcome variable then tends to be taken up by other health deficits included.

We assess the sensitivity of our results with two alternative indicators of physiological functioning. The first indicator counts the number out of 10 limitations in activities of daily living (difficulties with dressing oneself, eating, bathing, walking across the room, and using the toilet) and instrumental activities of daily living (difficulties with shopping groceries, preparing hot meals, managing money, taking medication, and using a phone). We define limited functioning as having two or more limitations in these activities, capturing the lower end of the physiological functioning distribution, which is correlated with long-term care needs (Katz 1983). The second indicator uses variation in cognitive functional capacity in terms of memory (immediate and delayed word recall) and concentration (repeated mathematical subtractions in Serial 7's test) to differentiate between people at higher levels of physiological functioning.

3.4 Patterns and Trends in Physiological Functioning

We begin analyzing the linkage between chronological age and physiological functioning by regressing the logarithm of a person's frailty index on a constant and chronological age. This parsimonious model is consistent with the approximately log-linear relationship between age-specific mortality rates and chronological age for older adults first observed by Gompertz (1825) and is commonly used in analysis of physiological aging (e.g., Abeliansky and Strulik 2018).

The results in Table 1 show a significant and positive association between chronological age and frailty. Health deficits increase at an estimated rate of 2.4–4.5 percent per year of age, consistent with previous studies (Strulik 2023). However, the R^2 for the parsimonious specification is low,

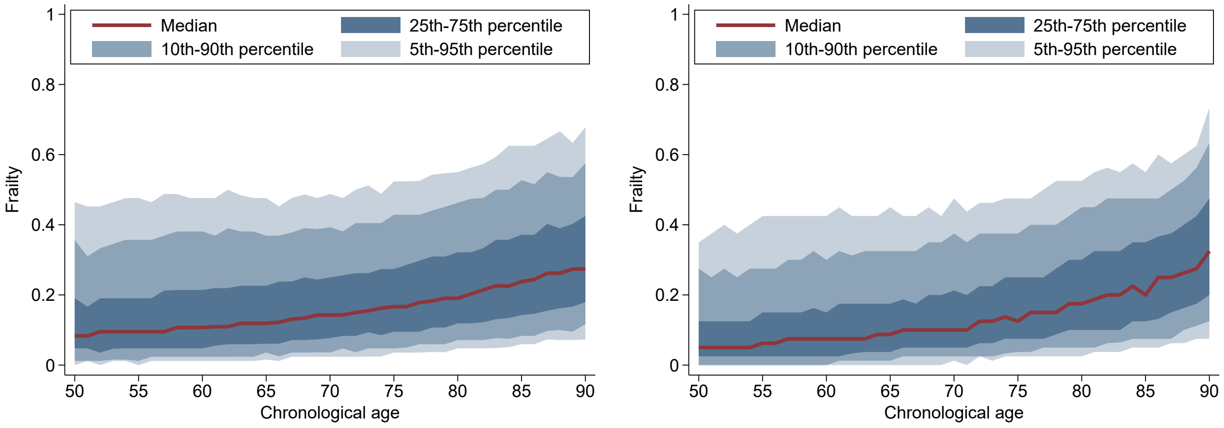
Table 1: Predictive power of chronological age for physiological functioning at the individual level

	Health and Retirement Study			English Longitudinal Study of Ageing		
	No controls	Fixed effects	Fixed effects & lagged frailty	No controls	Fixed effects	Fixed effects & lagged frailty
	(1)	(2)	(3)	(4)	(5)	(6)
Age	0.024***	0.045***	0.037***	0.029***	0.036***	0.035***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Log frailty	—	—	0.186***	—	—	0.029***
(lagged)	—	—-	(0.004)	—	—	(0.006)
R^2	0.07	0.79	0.80	0.09	0.79	0.79
Respondents	25,992	25,992	25,992	10,402	10,402	10,402
Observations	156,133	156,133	156,133	51,045	51,045	51,045

Note: This table shows the predictive power of chronological age for physiological functioning in terms of the log frailty index. Estimates are obtained from ordinary least squares. The dependent variable is the logarithmized frailty index. Specifications (1) and (4) include no control variables, specifications (2) and (5) add respondent fixed effects, and (3) and (6) control for respondent fixed effects and lagged log frailty. Standard errors are clustered at the respondent level and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

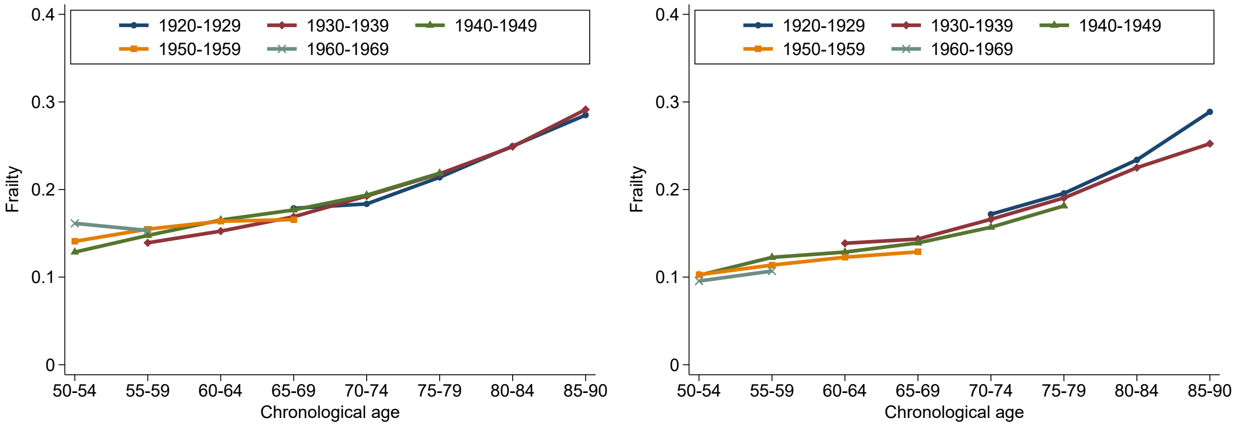
with chronological age explaining only 7–9 percent of the variation in health deficits. This result indicates appreciable heterogeneity in physiological functioning at each chronological age. Including respondent fixed effects raises the proportion of variation the model can explain to 79 percent. Hence, chronological age correlates with physiological functioning at the individual level, but its predictive power for physiological aging is small compared with other individual-specific factors. Finally, the pace at which people accumulate health deficits tends to increase with the number of health deficits they already have. According to the estimates, health deficits increase by 0.03–0.19 percent for every additional percent of health deficits in the preceding period, which points to widening heterogeneity in frailty as chronological age increases.

We next inspect the frailty index at different percentiles to gauge the extent to which people differ in how they age. Figure 1(a) documents evidence of heterogeneity in physiological functioning for the United States. According to the interquartile range, half the population aged 50 has between 2 and 8 health deficits and the variation is even wider when considering the tails of the distribution: the frailest 5 percent have 20 or more health deficits, whereas the healthiest 5 percent have none. Heterogeneity in physiological functioning increases with chronological age. At age 90, half the population has between 7.5 and 18 health deficits and 90 percent between 3 and 29. Accordingly, chronological age tends to become less informative with respect to physiological functioning with the increasing age of a person. Moreover, some people preserve high levels of physiological functioning into the older ages, while others are already frail at younger ages. The healthiest 10 percent of the population at age 90 have only 1 more health deficit than the median person at age 50, and the healthiest 25 percent have fewer health deficits than the least healthy 25 percent at age 50. Figure 1(b) shows qualitatively similar but quantitatively different patterns for England. Notably, morbidity is more compressed than in the United States. According to the interquartile range, half the population has between 1 and 5 health deficits at age 50 but between 8 and 20 at age 90.



(a) Frailty distribution by age: United States

(b) Frailty distribution by age: England



(c) Average frailty by age and cohort: United States

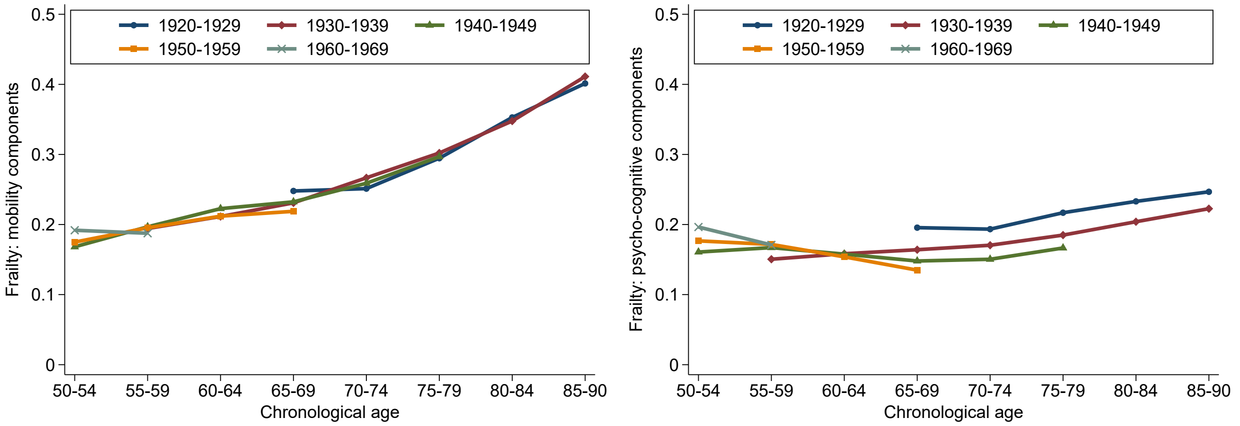
(d) Average frailty by age and cohort: England

Figure 1: Physiological functioning in the United States and England

Note: This figure shows patterns and trends in physiological functioning, as measured by the frailty index, in the United States and England. Panels (a) and (b) show frailty levels conditional on chronological ages for different percentiles. Panels (c) and (d) present frailty levels conditional on chronological ages across five birth decades, covering the 1920s to the 1960s. Observations are weighted by sampling weights to achieve ex-post representativeness.

To examine malleability of the rate at which people age, we compare average frailty levels conditional on chronological age across the five birth decades from the 1920s to the 1960s. We group respondents in five-year age groups, such that age–cohort cells average 8,030 observations (minimum 1,413) in the United States and 3,358 observations (minimum 448) in England.

Conditional on chronological age, average frailty levels have improved across birth cohorts in England (Figure 1d) but not in the United States (Figure 1c). Counting all improvements from the youngest to the oldest cohort in England suggests average frailty levels have decreased by 2–3 health deficits. In contrast, the age–cohort patterns in frailty for the United States overlap, indicating no



(a) Frailty by age and cohort: mobility components (b) Frailty by age and cohort: psycho-cognitive components

Figure 2: Age patterns in physiological functioning across different domains in the United States

Note: This figure shows age patterns in physiological functioning, as measured by a frailty index, in the mobility and psycho-cognitive domains across five birth decades, covering the 1920s to the 1960s. Observations are weighted by sampling weights to achieve ex-post representativeness.

improvement and, if anything, a slight increase in health deficits among younger age cohorts. Taken together, these results highlight that average physiological functioning for a given chronological age can improve, stagnate, or deteriorate over time.

The frailty index aggregates health deficits across various domains. To examine whether the age patterns in physiological functioning vary across these domains, we compute subindices based on the mobility (12 survey items) and psycho-cognitive components (10 survey items) for the United States. We separate the components in this way to differentiate between age patterns in physical and cognitive functioning, although the two are clearly connected (Buchman et al. 2011).

The mobility components show similar age–cohort patterns as the broader frailty index and no improvement across birth cohorts (Figure 2a). In contrast, the patterns for the psycho-cognitive components document improvements in physiological functioning across the 1920s to 1950s birth cohorts in the age range 65–90 and slight declines for the youngest age cohorts (Figure 2b). We find similar differences in the age patterns of mobility and psycho-cognitive functioning for England, except that physiological functioning continually improves across birth cohorts (Figure A.1).

The empirical evidence casts doubt on the use of chronological age as a reliable indicator for physiological functioning. Chronological age is a weak indicator of individual frailty, which poses a major challenge for policy design, especially concerning employment of older workers (see Berkman and Truesdale 2022). Moreover, shifts in the age patterns of physiological functioning across birth cohorts imply that the economic consequences of population aging cannot be readily inferred from chronological measures of aging. Finally, the fact that physiological functioning trends differentially across different domains means that investigations into the responses to population aging require a nuanced approach to the measurement of aging that goes beyond chronological age.

In keeping with much of the literature, we do not correct for biases associated with non-random attrition including survivor effects. However, such patterns do not seem to be a severe concern in the Health and Retirement Study or the English Longitudinal Study of Ageing (Banks et al. 2011).

4 Age and Physiological Functioning in Economic Analyses

Our results suggest chronological age approximates physiological functioning imperfectly at best. We next examine whether chronological age can nonetheless serve as a proxy for physiological functioning in economic analyses. To this end, we assess whether chronological age predicts the effects of physiological functioning on economic behaviors and outcomes when used as a substitute and compare the predicted effects of chronological age and physiological functioning in specifications that include either variable jointly. For our assessment, we supplement our data by drawing on the Consumption and Activities Mail Survey, which some participants in the Health and Retirement Study answer in off-survey years (HRS 2023a). We consider labor supply at the extensive and intensive margins; labor productivity in terms of hourly wages; productive nonmarket activities such as volunteering and helping others; life satisfaction; and medical outcomes, as measured by out-of-pocket medical expenditures and an indicator of whether a person lives in a nursing home or stayed overnight in a hospital in the previous two years.

We model a behavior or outcome y of a respondent i observed at time t as a linear function of physiological functioning x in terms of our frailty index, controls w for work experience and census regions, respondent fixed effects δ, period effects ζ, and an error term ε; where α is a constant and γ and ϕ denote parameters:

$$y_{it} = \alpha + \phi x_{it} + w_{it}' \gamma + \delta_i + \zeta_t + \varepsilon_{it}. \tag{1}$$

We further assume physiological functioning and chronological age a are correlated, such that

$$x_{it} = \rho a_{it} + \nu_{it}, \tag{2}$$

where ν_{it} is an error term and $\rho \neq 0$. We define $\beta = \phi \cdot \rho$. This notation implicitly assumes that chronological age has no effect on y except through x. Indeed, the literature review suggests chronological age might independently affect economic behaviors and outcomes and should be included in equation (1). However, in this case, chronological age would be an unsuitable proxy for physiological functioning because we would not be able to discern the effects of physiological from chronological aging. We proceed with the assumption under the null hypothesis that chronological age is a suitable proxy for physiological functioning and test whether we can maintain it.

By controlling for respondent fixed effects, we account for characteristics that may correlate with dependent and independent variables, such as educational attainment, statutory retirement ages (which are linked to year of birth), ethnicity, gender, and phenotypes. Occupational change is a potential pathway for physiological functioning to affect economic behaviors and outcomes, which we deliberately allow in our analysis. We fit the empirical model using logistic regressions if the dependent variable is binary and with ordinary least squares otherwise.

Our analysis concentrates on the parameters β and ϕ, which inform us about the extent to which chronological age and physiological functioning influence economic behaviors and outcomes. Suppose chronological age captures all relevant information about physiological functioning in our data. Then, if physiological functioning determines an outcome ($\phi \neq 0$), chronological age should also predict this outcome if the empirical model does not account for physiological functioning ($\beta \neq 0$). Likewise, if physiological functioning does not determine an outcome ($\phi = 0$), chronological age should not predict the outcome if the empirical model does not account for physiological functioning ($\beta = 0$). Finally, the inclusion of chronological age should not provide additional information for the prediction of the dependent variable compared to a model that already accounts for physiological functioning: that is, both variables should not be significant concomitantly.

Table 2 reports results for specifications that include only chronological age (Panel a), specifications that jointly include chronological age and physiological functioning (Panel b), and average marginal effects for the statistically preferred model with the lowest prediction error (Panel c).

The results demonstrate that chronological age is an unreliable proxy for physiological functioning in predicting economic behaviors and outcomes (Panels a and b). Whereas chronological age only correlates significantly with labor supply and medical outcomes, frailty is associated with all outcome variables except for hourly wages. Hence, chronological age does not detect the effects of physiological functioning on productive nonmarket activities and life satisfaction when used as a proxy. Moreover, chronological age and physiological functioning contain different information as they predict labor supply and medical outcomes independently from one another. Accordingly, other age-related, non-physiological factors also influence the outcome variables. Finally, the inclusion of physiological functioning in the model barely changes the estimated coefficients of chronological age, indicating that chronological age is not a reliable control for physiological functioning.

One can improve the predictive power of chronological age for the outcome variables by including a quadratic term (Table A.3); however, this inclusion does not change the finding that chronological age and physiological functioning contain independent information. Notably, using quadratic or higher-order polynomial specifications of chronological age barely impacts the estimated effects of physiological functioning on economic behavior and outcomes (Table A.4), further

Table 2: Predictive power of chronological age and physiological functioning for select economic behaviors and outcomes

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
(a) Predictive power of chronological age								
Age	-0.09***	-0.24**	0.00	-0.01	0.04	-0.01	0.06***	0.17***
	(0.03)	(0.12)	(0.01)	(0.05)	(0.04)	(0.02)	(0.01)	(0.02)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.72	0.47	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099
(b) Predictive power of chronological age and physiological functioning								
Age	-0.09***	-0.24*	0.00	-0.01	0.05	-0.01	0.05***	0.16***
	(0.03)	(0.12)	(0.01)	(0.05)	(0.04)	(0.02)	(0.01)	(0.02)
Functioning	-4.58***	-3.97***	-0.03	-2.12***	-1.99***	-2.74***	1.79***	3.35***
	(0.15)	(0.96)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.73	0.48	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099
(c) Average marginal effects of age and physiological functioning in statistically preferred model								
Age	-0.004**	-0.24*	—	—	—	—	0.05***	0.00
	(0.002)	(0.12)	—	—	—	—	(0.01)	(0.00)
Functioning	-0.22***	-3.97***	-0.03	-0.41***	-0.36***	-2.74***	1.79***	0.00
	(0.04)	(0.96)	(0.05)	(0.07)	(0.04)	(0.12)	(0.05)	(0.00)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.73	0.48	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099

Note: This table shows the predictive power of chronological age and physiological functioning for labor supply (specifications 1 and 2), labor productivity (3), productive nonmarket activities (4 and 5), life satisfaction (6), and medical outcomes (7 and 8). Estimates are obtained from logistic regressions if the dependent variable is binary and from ordinary least squares (OLS) else. Specifications in Panel (a) include chronological age but not physiological functioning, whereas specifications in Panel (b) include both chronological age and functioning. Panel (c) reports average marginal effects for chronological age, frailty, or both for the statistically preferred model with the lowest prediction error. All specifications control for work experience and census region and include respondent fixed effects and period effects. Standard errors are clustered at the respondent level in OLS regressions and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

corroborating our concerns regarding the inferences chronological age can support about physiological functioning. The same concerns remain when omitting period effects from the regression model, which draw on similar variation as chronological age and are a potential source of multicollinearity (Table A.5). Our qualitative findings are also robust to the use of alternative measures of physiological functioning such as limitations in activities of daily living and instrumental activities of daily living and cognitive functional capacity (Table A.6).

The direction and magnitude of the implied economic effects of chronological age and physiological functioning vary across outcome variables. We assess these effects by computing the average marginal effects for the statistically preferred model (Panel c), where we select models based on the lowest prediction error (see Table A.7). A decline in physiological functioning decreases labor supply, the probability to volunteer and help others, and life satisfaction, and increases out-of-pocket medical spending and the probability of being institutionalized. A one-standard deviation increase in frailty (about 0.17 points of the frailty index) lowers the probability to work for pay by about 3.7 percentage points, usual hours worked per week by 0.67, the probabilities to volunteer and help others by 7.0 and 6.1 percentage points, and life satisfaction by 0.47 points on a scale of 1–7. In contrast, the same decline increases out-of-pocket medical spending by 30 percent. Increases in chronological age correlate with labor supply and medical outcomes. An additional year of age reduces the probability to work for pay by 0.4 percentage points and usual hours worked per week by 0.24 and raises out-of-pocket medical spending by 5 percent. While chronological age and frailty are prognostic of the probability of being institutionalized, the average marginal effect is close to zero and insignificant.

5 Concluding Remarks

A chronological concept of aging is widely used in analysis of population aging in research and policy. However, chronological age itself is not necessarily deeply informative about the underlying processes of aging, and its value in analysis hinges on its usefulness in tracking patterns and trends in physiological functioning. A review of economic literature in which aging issues are important suggests that chronological aging is only sometimes the relevant concept of aging and often it is used to approximate decline of physiological functioning. If chronological age is a poor proxy for the latter, it provides an inaccurate description of population aging.

We therefore investigated the extent to which chronological age can support inferences about people's aging-related functioning in physiological and economic terms. Using longitudinal data from the United States and England, we first assessed the distributional characteristics of physiological functioning conditional on chronological age to elucidate differences with respect to the pace at which people age. We then conducted regression analysis to test the extent to which chronological age and physiological functioning predict various economic behaviors and outcomes.

Our assessment demonstrates that chronological age does not reliably account for physiological functioning in economic analyses. We find that age patterns of physiological functioning differ appreciably across people, health domains, and over time. Moreover, we document that the information content of chronological age and physiological functioning are distinctly different. Chronological age is not only an unreliable proxy for physiological functioning but also captures economic effects of non-physiological factors (such as retirement policy).

Our findings raise concern over a reliance on chronological age as an indicator of aging. The features that propelled its use as a bureaucratic measure—simplicity, regularity, and interpersonal equivalence—are the characteristics that make it a poor indicator for the diverse ways people age. For instance, the fact that chronological age defines statutory retirement ages in public pension programs creates financial incentives that can drive the healthy and more affluent out of the workforce and keep the unhealthy and less affluent locked in. Given the growing proportion of older workers and the trend toward raising statutory pension ages, such patterns will have increasing distributional consequences. A continual focus on chronological age might thus prevent society from fully adapting to gains in life expectancy and realizing the full benefits of increased longevity.

For research, a key issue is to identify which dimension of aging is of interest and how to measure it. Our empirical results suggest a frailty index can predict the influences of physiological aging across several economic outcomes. However, to our knowledge, no consensus exists on how to best measure physiological aging. More work is needed to improve the measurement of physiological aging and our understanding of how it affects individuals and the economy.

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A Supplemental Appendix

Table A.1: Descriptive statistics

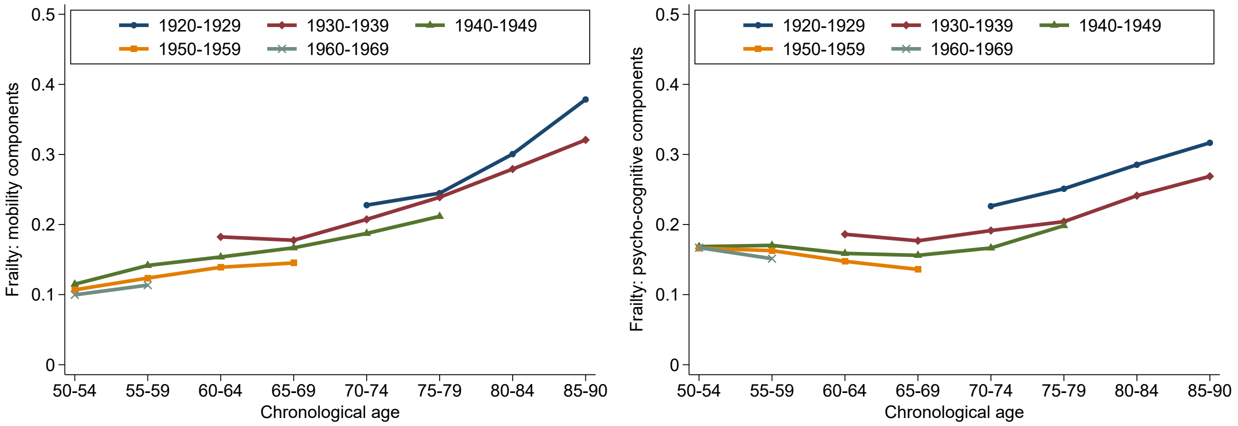
Variable (units)	Observations	Mean	Standard deviation	Minimum	Maximum
Functioning indicators: HRS					
Chronological age (in years)	205,778	67.48	10.11	50.00	90.00
Frailty index (on scale 0–1)	203,743	0.20	0.17	0.00	1.00
Limitations in ADL and IADL (yes/no)	205,448	0.23	0.42	0.00	1.00
Cognitive functional capacity (standardized)	192,470	0.00	0.81	-2.47	2.05
Functioning indicators: ELSA					
Chronological age (in years)	80,126	66.89	10.01	50.00	90.00
Frailty index (on scale 0–1)	79,943	0.15	0.15	0.00	0.93
Economic behavior and outcomes: CAMS					
Works for pay (yes/no)	205,234	0.37	0.48	0.00	1.00
Usual hours worked per week (in hours)	74,227	36.35	15.46	0.00	168.00
Hourly wage rate (in USD)	67,636	25.19	59.60	0.00	1919.50
Does volunteer work (yes/no)	46,119	0.30	0.46	0.00	1.00
Helps others (yes/no)	45,976	0.58	0.49	0.00	1.00
Life satisfaction (on scale 1–7)	39,183	4.90	1.53	1.00	7.00
Out-of-pocket medical expenditures (in thousand USD)	205,778	3.24	10.72	0.00	1206.58
Institutionalized in past 12 months (yes/no)	198,187	0.25	0.43	0.00	1.00
Control variables: HRS					
Work experience	205,778	31.91	15.88	0.00	77.00
Census region: Northeast	205,432	0.15	0.35	0.00	1.00
Census region: Midwest	205,432	0.25	0.44	0.00	1.00
Census region: South	205,432	0.42	0.49	0.00	1.00
Census region: West	205,432	0.18	0.38	0.00	1.00
Census region: Other	205,432	0.00	0.02	0.00	1.00

Note: This table shows descriptive statistics for functioning indicators from the Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA) and measures of economic behavior and outcomes from the Consumption and Activities Mail Survey (CAMS). Respondents are coded as limited in functioning if they have two or more limitations in either activities of daily living (ADL) or instrumental activities of daily living (IADL) or any possible combination of the two. In a small number of cases, hourly wages appear inconsistently large; we set hourly wages to missing in 51 cases in which they exceed 2,000 dollars (USD).

Table A.2: Items contained in frailty index

Item	Coding
Mobility	
Some difficulty walking several blocks	Yes = 1, No = 0
Some difficulty walking one block	Yes = 1, No = 0
Some difficulty sitting for 2 hours	Yes = 1, No = 0
Some difficulty getting up from a chair	Yes = 1, No = 0
Some difficulty climbing several flights of stairs	Yes = 1, No = 0
Some difficulty climbing one flight of stairs	Yes = 1, No = 0
Some difficulty kneeling, stooping, or crouching	Yes = 1, No = 0
Some difficulty lifting or carrying 10 pounds (mass)	Yes = 1, No = 0
Some difficulty picking up a dime	Yes = 1, No = 0
Some difficulty reaching or extending arms	Yes = 1, No = 0
Some difficulty pushing or pulling a large object	Yes = 1, No = 0
Activities of daily living	
Some difficulty getting dressed	Yes = 1, No = 0
Some difficulty walking across the room	Yes = 1, No = 0
Some difficulty taking a bath or shower	Yes = 1, No = 0
Some difficulty eating	Yes = 1, No = 0
Some difficulty getting in and out of bed	Yes = 1, No = 0
Some difficulty using a toilet	Yes = 1, No = 0
Instrumental activities of daily living	
Some difficulty reading a map	Yes = 1, No = 0
Some difficulty using a phone	Yes = 1, No = 0
Some difficulty managing money	Yes = 1, No = 0
Some difficulty taking medications	Yes = 1, No = 0
Some difficulty shopping for groceries	Yes = 1, No = 0
Some difficulty preparing hot meals	Yes = 1, No = 0
Depression	
Felt depressed	Yes = 1, No = 0
Felt everything was an effort	Yes = 1, No = 0
Sleep was restless	Yes = 1, No = 0
Felt happy	Yes = 0, No = 1
Felt lonely	Yes = 1, No = 0
Felt sad	Yes = 1, No = 0
Could not get going	Yes = 1, No = 0
Enjoyed life	Yes = 0, No = 1
Doctor diagnosed health problems	
Ever had high blood pressure	Yes = 1, No = 0
Ever had diabetes	Yes = 1, No = 0
Ever had cancer	Yes = 1, No = 0
Ever had lung disease	Yes = 1, No = 0
Ever had heart disease	Yes = 1, No = 0
Ever had stroke	Yes = 1, No = 0
Ever had psychological problems	Yes = 1, No = 0
Ever had arthritis	Yes = 1, No = 0
Cognition	
Delayed word recall (out of 10 words)	≤ 2 words = 1, > 2 words = 0
Immediate word recall (out of 10 words)	≤ 4 words = 1, > 4 words = 0
Body mass index (BMI)	
BMI	BMI ≥ 30 or BMI $\leq 18.5 = 1$, $25 \leq$ BMI $< 30 = 0.5$, $18.5 <$ BMI $< 25 = 0$

Note: This table lists all items that are included in the frailty index and shows how they are coded.



(a) Frailty by age and cohort: mobility components (b) Frailty by age and cohort: psycho-cognitive components

Figure A.1: Age patterns in physiological functioning across different domains in England

Note: This figure shows age patterns in functioning, as measured by a frailty index, in the mobility and the psycho-cognitive domains across five birth decades, covering the 1920s to the 1960s. Observations are weighted by sampling weights to achieve ex-post representativeness.

Table A.3: Predictive power of chronological age and physiological functioning for select economic behaviors and outcomes: Quadratic specification of age

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
(a) Predictive power of chronological age								
Age	-0.15***	0.92***	-0.01	0.43***	0.37***	0.14***	0.02**	0.07***
	(0.04)	(0.20)	(0.01)	(0.06)	(0.05)	(0.03)	(0.01)	(0.02)
Age squared	0.0004**	-0.009***	0.00	-0.003***	-0.002***	-0.001***	0.0003***	0.001***
	(0.0002)	(0.001)	0.00	(0.000)	(0.000)	(0.000)	(0.0001)	(0.0001)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.68	0.72	—	—	0.72	0.47	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099
(b) Predictive power of chronological age and physiological functioning								
Age	-0.21***	0.89***	-0.01	0.40***	0.34***	0.09***	0.06***	0.14***
	(0.04)	(0.20)	(0.01)	(0.06)	(0.05)	(0.03)	(0.01)	(0.02)
Age squared	0.001***	-0.01***	0.00	-0.003***	-0.002***	-0.001***	-0.00	0.00
	(0.000)	(0.00)	(0.00)	(0.000)	(0.000)	(0.000)	(0.00)	(0.00)
Functioning	-4.65***	-3.40***	-0.03	-1.70***	-1.75***	-2.66***	1.80***	3.33***
	(0.15)	(0.96)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.68	0.72	—	—	0.73	0.48	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099

Note: This table shows the predictive power of chronological age and physiological functioning for labor supply (specifications 1 and 2), labor productivity (3), productive nonmarket activities (4 and 5), life satisfaction (6), and medical outcomes (7 and 8). Estimates are obtained from logistic regressions if the dependent variable is binary and from ordinary least squares (OLS) else. Specifications in Panel (a) include chronological age but not functioning, whereas specifications in Panel (b) include both chronological age and functioning. All specifications control for work experience and census region and include respondent fixed effects and period effects. Standard errors are clustered at the respondent level in OLS regressions and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.4: Predictive power of physiological functioning for economic behaviors and outcomes: Accounting for higher-order polynomial specifications of chronological age

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
(a) Linear specification of age effects								
Functioning	-4.58***	-3.97***	-0.03	-2.12***	-1.99***	-2.74***	1.79***	3.35***
	(0.15)	(0.96)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
(b) Quadratic specification of age effects								
Functioning	-4.65***	-3.40***	-0.03	-1.70***	-1.75***	-2.66***	1.80***	3.33***
	(0.15)	(0.96)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
(c) Cubic specification of age effects								
Functioning	-4.68***	-4.02***	-0.04	-1.61***	-1.72***	-2.65***	1.77***	3.37***
	(0.15)	(0.95)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
(d) Quartic specification of age effects								
Functioning	-4.75***	-4.01***	-0.04	-1.61***	-1.72***	-2.65***	1.77***	3.37***
	(0.15)	(0.95)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099

Note: This table shows the predictive power of physiological functioning for labor supply (specifications 1 and 2), labor productivity (3), productive nonmarket activities (4 and 5), life satisfaction (6), and medical outcomes (7 and 8). Estimates are obtained from logistic regressions if the dependent variable is binary and from ordinary least squares (OLS) else. Specifications account for chronological age effects that are linear (Panel a), quadratic (b), cubic (c), or quartic (d). All specifications control for work experience and census region and include respondent fixed effects and period effects. Standard errors are clustered at the respondent level in OLS regressions and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.5: Predictive power of chronological age and physiological functioning for select economic behaviors and outcomes: No period effects

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
(a) Predictive power of chronological age								
Age	-0.56***	-1.51***	-0.03***	-0.08***	-0.14***	0.00	0.04***	0.06***
	(0.01)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.72	0.46	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099
(b) Predictive power of chronological age and physiological functioning								
Age	-0.53***	-1.49***	-0.03***	-0.06***	-0.12***	0.02***	0.02***	0.03***
	(0.01)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Functioning	-4.62***	-4.52***	-0.02	-2.03***	-2.01***	-2.75***	1.89***	3.38***
	(0.15)	(0.96)	(0.05)	(0.24)	(0.19)	(0.12)	(0.05)	(0.08)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.73	0.47	—
Respondents	12,337	15,326	14,397	3,380	5,036	12,128	27,681	18,522
Observations	102,986	70,373	62,785	21,741	31,606	32,662	173,851	136,099

Note: This table shows the predictive power of chronological age and physiological functioning for labor supply (specifications 1 and 2), labor productivity (3), productive nonmarket activities (4 and 5), life satisfaction (6), and medical outcomes (7 and 8). Estimates are obtained from logistic regressions if the dependent variable is binary and from ordinary least squares (OLS) else. Specifications in Panel (a) include chronological age but not functioning, whereas specifications in Panel (b) include both chronological age and functioning. All specifications control for work experience and census region and include respondent fixed effects. Standard errors are clustered at the respondent level in OLS regressions and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.6: Predictive power of physiological functioning in terms of limitations in ADL and IADL and cognitive functional capacity

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
(a) Limitations in ADL and IADL								
Age	-0.10***	-0.25**	0.00	-0.01	0.04	-0.01	0.06***	0.17***
	(0.03)	(0.12)	(0.01)	(0.05)	(0.04)	(0.02)	(0.01)	(0.02)
Functioning	-0.65***	-1.00***	-0.01	-0.32***	-0.32***	-0.31***	0.27***	0.47***
	(0.03)	(0.22)	(0.01)	(0.06)	(0.05)	(0.03)	(0.01)	(0.02)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.67	0.72	—	—	0.72	0.48	—
Respondents	12,366	15,348	14,417	3,384	5,043	12,143	27,842	18,671
Observations	103,472	70,529	62,891	21,771	31,670	32,701	175,182	137,324
(b) Cognitive functional capacity								
Age	-0.10***	-0.22*	0.00	-0.00	0.05	-0.02	0.05***	0.16***
	(0.03)	(0.13)	(0.01)	(0.05)	(0.04)	(0.02)	(0.01)	(0.02)
Functioning	0.09***	0.08	-0.01	0.18***	0.15***	0.05***	-0.04***	-0.12***
	(0.02)	(0.10)	(0.01)	(0.03)	(0.03)	(0.02)	(0.01)	(0.01)
Model	Logit	OLS	OLS	Logit	Logit	OLS	OLS	Logit
R^2	—	0.68	0.72	—	—	0.72	0.48	—
Respondents	11,856	14,762	13,953	3,314	4,885	11,918	26,487	17,531
Observations	97,216	67,122	60,556	21,256	30,688	32,158	164,036	127,606

Note: This table shows the predictive power of chronological age and physiological functioning for labor supply (specifications 1 and 2), labor productivity (3), productive nonmarket activities (4 and 5), life satisfaction (6), and medical outcomes (7 and 8). Estimates are obtained from logistic regressions if the dependent variable is binary and from ordinary least squares (OLS) else. In Panel (a), functioning is measured in terms of limitations in activities of daily (ADL) or instrumental activities of daily living (IADL), where respondents are coded to be limited in functioning if they have two or more limitations in either ADL, IADL, or any possible combination of the two. In Panel (b), functioning is measured in terms of cognitive functional capacity, which is a composite indicator constructed from respondents' performance in tests of memory (immediate and delayed word recall) and concentration (repeated mathematical subtractions in Serial 7s test). All specifications control for work experience and census region and include respondent fixed effects and period effects. Standard errors are clustered at the respondent level in OLS regressions and reported in parentheses. Asterisks indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.7: Model selection based on prediction error

Dependent variable	Work for pay (1)	Working hours (2)	Log hourly wage (3)	Volunteer work (4)	Help others (5)	Life satisfaction (6)	Log medical out-of-pocket spending (7)	In nursing home or hospital (8)
Age & functioning	46,798.0	505,271.0	71,714.9	16,573.7	23,915.8	77,140.7	501,030.3	102,533.7
Age only	47,834.9	505,301.5	71,713.4	16,652.5	24,025.3	78,286.6	504,124.7	104,458.1
Functioning only	46,806.0	505,274.3	71,713.2	16,571.8	23,915.3	77,139.1	501,069.0	102,604.7

Note: This table shows estimates of the prediction error, as measured by the Akaike information criterion, for specifications that either control only for chronological age, only for physiological functioning, or both. Model specifications with lower prediction errors are preferable. Logistic regressions are fitted if the dependent variable is binary and ordinary least squares regressions else. All specifications include respondent, census region, and period effects.