The Value of Healthy Longevity and Increasing Returns to Tackling Ageing

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Abstract

In the 20th century, the US benefited from remarkable improvements in health and longevity. In contrast, despite rising health expenditure, the 21st century has seen a deterioration in U.S health capital. Using a novel approach to clustering diseases we show this slowdown coincides with the increased dominance of ageing-related diseases and that future substantive improvements in U.S health capital requires tackling the root causes of these ageing-related diseases. The dominance of ageing-related diseases rests on two unique features. The first is a complementarity between morbidity and mortality, such that ageing-related diseases are a major cause of both death and ill-health. The second is an increasing returns mechanism whereby the greater the improvements in tackling ageing-related diseases, the more valuable further improvements become. We show analytically and numerically that increasing returns arises through an extensive margin connected to survival curves and their effect on life expectancy, population size and age structure. Our results point to the importance of compressing morbidity rather than boosting life expectancy; a focus on health rather than treating disease and a prioritisation of understanding the biology of ageing.

Keywords: Ageing, Disease, Health, Life Expectancy, Longevity, Value of Statistical Life, Willingness to Pay

JEL Classification : I1, I3, J1

1 Introduction

One of the greatest achievements of the twentieth century was a remarkable increase in life expectancy. In the U.S, life expectancy at birth rose from 49.3 in 1901 to 76.8 in 2000. Infant mortality fell from one in six children not living to see their first birthday to only one in one hundred and fifty. Substantial improvements were also achieved in adult mortality. For instance, age adjusted mortality rates from cardiovascular disease more than halved over the 20th century. In a seminal paper, Murphy and Topel (2006) show the monetary value of these gains to health and longevity to be substantial. Across the 20th century, these improvements in health capital are estimated to be the equivalent of around 40% of GDP per capita.

However, in the twenty first century the record is far less encouraging. Whilst life expectancy continues to increase globally, its rate of increase is slowing (Ashwin and Scott, 2025), especially in the United States. Between 2000 and 2023, US life expectancy increased by only two and a half years, from 76.8 to 79.3, even decreasing in several years, as emphasised by Case and Deaton (2022). In addition to slowing life expectancy gains, the World Health Organisation estimates that over this time period Healthy Life Expectancy in the U.S *fell* by 1.4 years, leading to an increase in the number of years spent in poor health

Reflecting these trends, Table 1 updates the estimates of Murphy and Topel (2006) for the U.S from 1990

to 2023 and shows a substantial deterioration. Since 2010, US health capital has declined substantially and the magnitude of the declines are far in excess of any increase in US GDP per capita.

Table 1: Averages of GDP and Annual Production of Health Capital per Capita, 1990–2023 (2019 Dollars)

	1990–2000	2000–10	2010–19	2019–2023
GDP per capita	$42,663	$52,231	$58,832	$65,244
Health capital per capita	$6,659	$12,920	-$7,146	-$37,321
Total	$49,322	$65,151	$51,686	$27,923
Share of health capital	.13	.20	-0.14	-1.34

Across high income countries a related pattern is emerging. Life expectancy gains are slowing but broadly the proportion of life spent in good health is constant (Hay, 2025). The consequence is an expansion of the number of years at the end of life spent in poor health and an epidemiological transition characterised by a dramatic shift in the disease burden away from infectious towards chronic diseases (Omran, 1971).

These trends raise a number of important issues that are the subject of this paper. In particular, are the gains from life expectancy increases coming to an end given the rising number of years at the end of life spent in poor health? Is a focus on intervening to treat disease that drove improvements in the 20th century still optimal given the growing importance of ageing-related disease? The economic implications of these questions are substantial. The deterioration in US health capital in the 21st century has coincided with a rise in US health expenditure from 13.3% of GDP to 17.8%, an increase in per capita health expenditure of over 80%. Given the financial sums involved and the welfare importance of health these are topics of first order economic importance.

In this paper, we attempt to answer these questions by building on the analysis of Rosen (1988), Murphy and Topel (2006), Scott et al. (2021) and Scott et al. (2023) by introducing the clustering approach of Ashwin et al. (2026). This clustering approach has two key features. First, it seeks to reduce the dimensionality of the burden of disease by a clustering algorithm that groups diseases into a few major categories. Second, we cluster diseases based on their burden over the life cycle and arrive at four distinct categories - infant, early adult, later adult and ageing-related diseases. The first three are defined by the timing of the peak in their burden whilst ageing-related diseases are characterised by a burden that increases continually with age.

The motivation for defining diseases with reference to the life cycle is to link shifts in the disease burden with a global demographic transition. Because of gains to life expectancy and declines in fertility, the population age structure is changing dramatically. In 1900, 4% of the US population were aged over 65 and only 0.5% aged over 80. In 2023 these proportions are 18% and 3.5% respectively and are projected to reach 25% and 8% by 2060 (Congressional Research Service, 2024). As a consequence of linking the disease burden to the life cycle we can provide a dynamic perspective on the analysis of Murphy and Topel (2006), providing insight as to why the gains in health capital have diminished,identifying where potential large gains from future health investment can arise from and where economic resources should be focused.

We find that because of life expectancy gains and shifts in the population age structure, ageing-related diseases (which are distinct from chronic diseases) are by far the largest component of the current disease burden. Crucially, ageing-related diseases are distinct from other disease clusters due to a complementarity between health and mortality. Whereas other diseases tend to be either a cause of death *or* ill-health, ageing-related diseases impact both leading to especially large gains from reducing their prevalence due to a multiplicative effect between morbidity and mortality. However, the key result of our paper is the finding of increasing returns to reducing the prevalence of ageing-related diseases. In other words, the better we get at ageing well, the more valuable further improvements in ageing are. The magnitude of this channel is unique to ageing-related diseases. We show mathematically and numerically that this arises from properties of life

expectancy and end of life mortality that interact in a unique way with ageing-related diseases. Past progress in reducing non-ageing related diseases have led to substantial gains in life expectancy. Life expectancy is now at a level where further improvements in health and longevity require a focus on ageing-related diseases. The greater the gains made in how we age, the more that ageing well increases in importance.

The implications of our analysis for the health system are profound. They suggest that a focus on treating disease to increase life expectancy may have been optimal in the 20th century but no longer is given the dominance of ageing-related diseases. Instead, greater gains to health capital come from slowing the prevalence of all ageing-related diseases eg achieving healthy longevity and a focus on preserving health rather than treating disease when it emerges. The gains from doing so, both in terms of life expectancy, healthy life expectancy and their economic value are substantial.

The paper is structured as follows. In Section 2 we outline our data and our disease clustering approach. In Section 3 we incorporate these clusters into the framework of Rosen (1988) and Murphy and Topel (2006) and calculate the relative value of reducing the prevalence of each cluster. In Section 4 we show analytically why ageing-related diseases are characterised by increasing returns and the sub-optimality of a health system focused on extending life expectancy rather than tackling ageing. A final Section concludes.

2 Data and Disease Clustering

At the heart of our approach is categorising diseases into distinct clusters based on the distribution of the disease burden over the life cycle. We use the latest release of the Global Burden of Disease (GBD) dataset (Global Burden of Disease Collaborative Network, 2025), which provides comprehensive estimates of the mortality and disability impact of 305 diseases and injuries from 1990 to 2023. Our analysis focuses specifically on the United States, and we utilize the most granular age groups available in the GBD data.[1] The GBD quantifies the non-fatal burden of disease using a combination of prevalence data and disability weights, which capture the degree of health loss associated with each condition. These data are combined with mortality estimates to compute disability-adjusted life years (DALYs) - a summary measure representing the total years lost through ill-health and premature death.

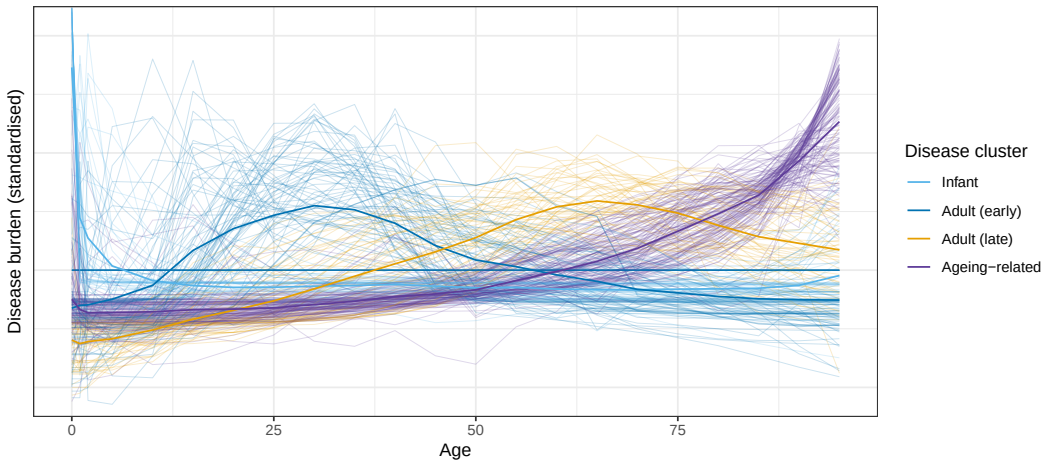
Following Ashwin et al. (2026), we employ a K-means++ unsupervised clustering algorithm to group diseases according to their DALY burden across age groups - that is, the number of DALYs lost per person at each age. We use data from 2023 to construct these clusters. To ensure that clustering is driven solely by the age pattern of disease burdens rather than absolute levels, we standardize DALY rates to have zero mean and unit variance.

We find four disease clusters provide a parsimonious and interpretable classification of diseases for the U.S. [2] Figure 1 displays the standardized burden for each cluster by age, with solid lines representing the cluster centroids and fainter lines showing individual diseases within each cluster. Based on the age profile of the burden, we label these clusters *ex post* as "infant," "adult (early)," "adult (late)," and "ageing-related." These labels reflect the revealed timing of peak burden over the life cycle, rather than underlying biological mechanisms or any identification assumptions imposed on the algorithm. The first three clusters are identified by the stages of life at which the disease burden is highest, while ageing-related diseases are characterized by a burden that rises broadly monotonically with age. Our clustering is agnostic to etiology; diseases in the same cluster need not share any biological relationship e.g we are not imposing a common single ageing-pathway on our ageing-related cluster consistent with the idea of multiple ageing mechanisms (López-Otín et al., 2023).

[1] These age categories are 0–1 years, 1–2 years, 2–4 years, and then 5 year age ranges from 5–9 years up to 95+.

[2] Crucially our finding of increasing returns and the dominance of ageing-related diseases are robust across a variety of assumptions about the number of clusters. Our algorithm classifies Covid as an ageing-related disease but for the purposes of our analysis we exclude it from our calculations to ensure that our findings are not dependent on the Covid pandemic. Our findings are also robust to the year selected to classify the disease clusters

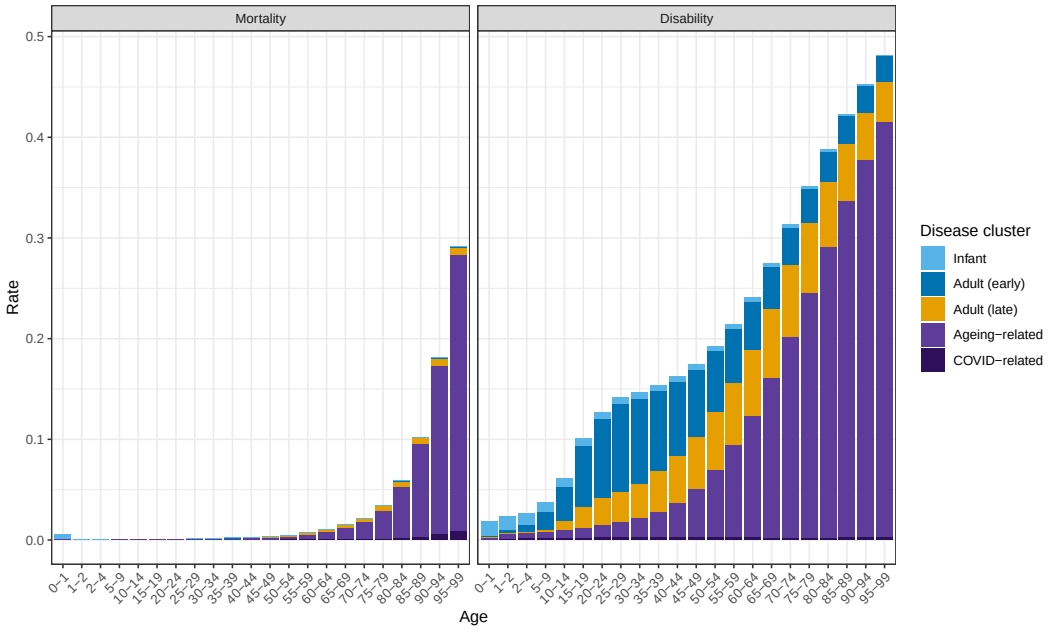
Figure 1: Disease clustered by DALY burden for US in 2023



Ashwin et al. (2026) provide comprehensive details on the allocation of diseases across clusters. Ageing-related diseases include, *inter alia*, ischemic heart disease and multiple other cardiovascular diseases, chronic obstructive pulmonary disease, diabetes Type 2, Parkinsons and dementia plus a number of cancers. Whilst ageing-related diseases are mainly chronic diseases (given we have excluded Covid from the cluster) not all chronic diseases are ageing related e.g ovarian, cervical and live cancer, Motor Neuron disease and Multiple Sclerosis are all classified as late adult diseases. Overall, only around half of chronic diseases are classified as ageing related.

Figure 2 shows global mortality and disability rates distributed across clusters by age. The very low level of mortality before age 50 reflects the historically high level of current life expectancy, aside from a small bulge in the first year of life reflecting infant mortality. Adult diseases (both early and late) affect disability more than mortality, while ageing-related diseases account for the majority of mortality risk. Adult diseases (early and late) explain the majority of disability from ages 15 to around 60 at which point ageing-related diseases dominate. As Figure 2 shows, ageing-related diseases are characterised by a high correlation between morbidity and mortality risk. In other words, whilst most diseases either contribute to mortality or ill-health, ageing related diseases contribute to both.

Figure 2: Mortality and disability rates by disease cluster



Note:

Table 2 shows a historical decomposition from 1980 onwards of increases in remaining U.S life expectancy at birth and at age 60 due to mortality reductions in each disease category. The current dominance of ageing-related diseases in driving life expectancy gains at both ages is apparent. With life expectancy exceeding 70 throughout this time period the scope for other diseases to boost life expectancy is limited. This also explains why a slowdown in tackling ageing-related diseases explains most of the slowdown in life expectancy gains over this period.

Table 2: Increases in Remaining U.S Life Expectancy due to reduced mortality by disease cluster 1980-2023

	Age 0					Age 60				
Cluster	1980-90	1990-00	2000-10	2000-19	2019-23	1980-90	1990-00	2000-10	2000-19	2019-23
Infant	0.28	0.21	0.09	0.06	-0.01	0.00	0.00	0.00	-0.00	-0.00
Adult (early)	-0.08	0.29	0.04	-0.36	-0.32	-0.01	0.03	0.01	-0.04	-0.03
Adult (late)	0.04	0.09	0.23	0.25	0.06	-0.12	-0.01	0.16	0.17	0.05
Ageing-related	1.48	0.76	1.45	0.28	0.03	1.17	0.57	1.39	0.26	0.08
COVID-related	0.00	0.00	0.00	0.00	-0.17	0.00	0.00	0.00	0.00	-0.15
Total	1.71	1.36	1.83	0.22	-0.41	1.03	0.59	1.58	0.39	-0.04

3 Economic Valuation of Health and Longevity Gains

The previous section outlined our approach to disease classification and the growing importance of ageing-related disease in driving life expectancy and healthy life expectancy. However, to answer our key questions about the relative value of further gains to life expectancy and healthy life expectancy and the level and allocation of health expenditure we need to incorporate our epidemiological approach into an economic model. We do so using the framework and model of Rosen (1988) and Murphy and Topel (2006).

3.1 Model

We assume the existence of a representative individual of age a who chooses consumption $c(t)$ and labour supply $\ell(t)$ over their remaining life span to maximize expected lifetime utility:

$$U(a) = \mathbb{E}_a \int_a^\infty e^{-\rho(t-a)} H(t)\, u(c(t), \ell(t))\, S(a,t)\, dt, \tag{1}$$

They do so subject to a budget constraint that equates the present value of assets and expected lifetime income to consumption :

$$\mathbb{E}_a \left[A_a + \int_a^\infty e^{-r(t-a)} \big(w(t)(\bar{L} - \ell(t)) + b(t) - c(t)\big) S(a,t)\, dt \right] = 0. \tag{2}$$

Here, $S(a,t)$ denotes the probability of surviving from age a to age t, $H(t)$ represents the quality of health, and $u(c,\ell)$ is the period utility from consumption and leisure. Health acts as a *multiplier on period utility*, reflecting that better health amplifies the welfare derived from consumption and leisure. We assume *non-separable CES preferences* over c and ℓ, allow agents to save using fairly priced annuities. For simplicity, we set the discount rate equal to the interest rate ($r = \rho$).

From this framework, one can derive the *willingness to pay (WTP)* for marginal improvements in survival or health at age a:

$$wtp(a) = \int_a^\infty e^{-r(t-a)} \left[v(t)\, \Delta S(a,t) + S(a,t) \frac{\Delta H(t)}{H(t)} \frac{u(c(t),\ell(t))}{u_c(c(t),\ell(t))} \right] dt, \tag{3}$$

where

$$v(t) = \frac{u(c(t),\ell(t))}{u_c(c(t),\ell(t))} + w(t)(\bar{L} - \ell(t)) - c(t). \tag{4}$$

The first term in (4) captures the value of incremental gains to survival probability, while the second term captures the value of improvements in health quality. To obtain the *social WTP*, we scale individual WTP by the current age distribution of the U.S. population, summing across all ages to capture the aggregate economic value of health and longevity improvements. For health inputs, we proxy $H(t)$ using $1 -$ Years Lived with Disability (YLD) measure from the GBD.

We assign values to the key economic parameters and calibrate the model to match empirical benchmarks, most importantly the US Value of a Statistical Life (VSL). For simplicity, we set the pure rate of time preference and the real interest rate to $\rho = r = 0.02$, consistent with long-run US macroeconomic evidence. Preferences are represented by a non-separable CES utility function over consumption and leisure of the form:

$$u(z) = \frac{z^{1-1/\sigma} - z_0^{1-1/\sigma}}{1 - 1/\sigma}, \tag{5}$$

where

$$z = \left(\phi c^{1-1/\eta} + (1-\phi)\ell^{1-1/\eta} \right)^{\eta/(\eta-1)}. \tag{6}$$

Table 3 summarizes the key parameters used in the economic model. Where possible, parameter values are drawn from U.S. empirical evidence or standard calibrations in the literature.

Table 3: Key Parameters of the Economic Model

Parameter	Value	Description
ρ, r	0.02	Time preference rate, real interest rate
σ	1/1.5	Intertemporal elasticity of substitution
η	1.509	Elasticity of substitution between consumption and leisure
ϕ	0.224	Weight on consumption in utility composite
z_0	600	Subsistence level of consumption-leisure composite

To anchor the model in monetary units, we calibrate the level of the age-dependent wage profile so that the resulting life-cycle willingness to pay reproduces a US VSL of approximately $11.5 million (based on the Greenstone and Nigam (2020) update of the US Environmental Protection Agency (EPA) value for growth and inflation). Importantly, this calibration largely acts as a level shift in the model: it scales the units of WTP but does not affect the age profile of marginal values.

3.2 Gains from Reducing Disease Prevalence

To assess the economic value of addressing different categories of disease, we quantify the social willingness to pay (WTP) for progressive reductions in the prevalence of each disease cluster. Our counterfactual exercise proceeds as follows. For a given cluster, we consider a one percentage point reduction in disease prevalence at every age, relative to the 2023 age profile. This intervention induces proportional reductions in both the mortality and disability rates associated with diseases in that cluster. We also separately evaluate the contributions of mortality reductions and morbidity reductions, allowing us to isolate the channels through which welfare gains arise.

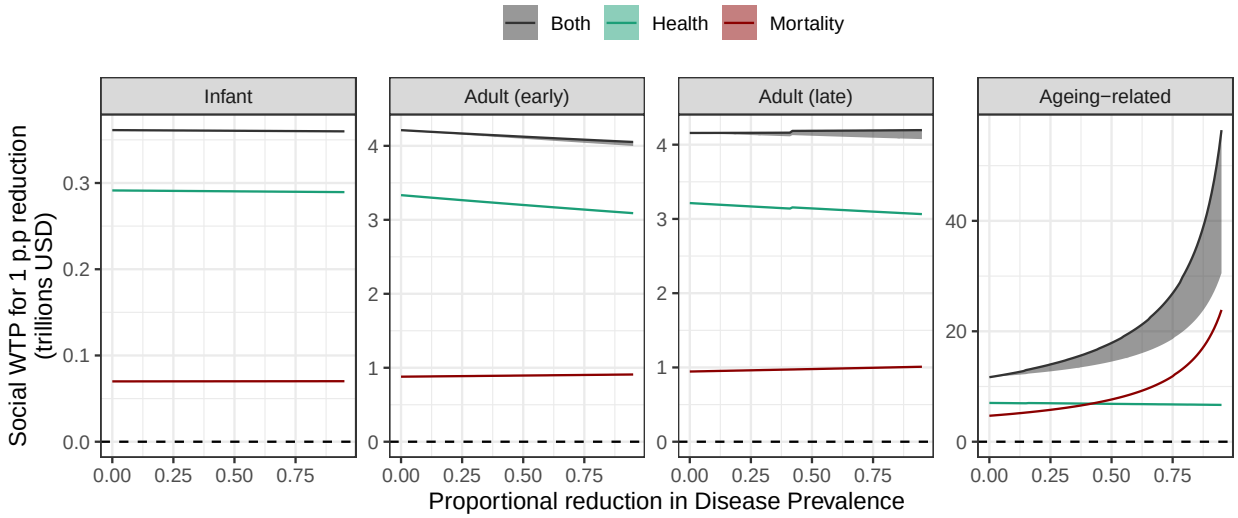
For each intervention, we compute the aggregate WTP of the current population, summing individual WTP across ages using the 2023 population distribution. We then repeat this exercise sequentially for successive one percentage point reductions in prevalence, allowing individuals to re-optimise consumption, labour supply, and savings decisions after each step, until the disease cluster is fully eliminated. To keep the magnitude of the reduction consistent these percentage points are always evaluated relative to the current mortality and disability rates (so after 100 percentage point reductions the disease cluster is fully eradicated). This allows us to capture the fact that the value of reductions in a disease cluster depend on how much that disease cluster has already been reduced - are the returns to tackling those diseases diminishing, constant or increasing?

Figure 3 plots the incremental social WTP associated with successive percentage point reductions in disease prevalence by cluster. Each panel represents the value of reducing prevalence of a different disease category, with the social WTP of the current US population shown on the vertical axis and the degree of reduction on the horizontal axis. The red line indicates the WTP if only the mortality effects of the disease cluster are reduced and the green line indicates the WTP if only the health effects of the disease cluster are reduced. The black line then indicates WTP if both mortality and health effects are reduced simultaneous. The shaded grey area illustrates the difference between the sum of WTP for the separate mortality and health improvement and the WTP for the simultaneous mortality and health improvement. This area can thus be interpreted as a complementarity between mortality and health improvements associated with the disease reduction. The headline results reveal striking differences across disease categories.

The first and most obvious result is the magnitude of gains from improvements in reducing the impact of ageing-related diseases. Every 1 percentage point reduction in the burden of ageing-related diseases is at least an order of magnitude large in its welfare benefits than is the case for the other clusters.

The second distinguishing feature is that for the non-ageing-related clusters, the social WTP exhibits approximately constant - or mildly diminishing - returns as prevalence is reduced. In other words, the more progress is made in reducing their prevalence the less important further improvements are. In contrast, interventions targeting ageing-related diseases display powerful increasing returns to scale: the marginal social value of additional reductions in prevalence rises sharply as the prevalence of these diseases is progressively lowered. As discussed below, this pattern holds even when improvements in health quality are excluded and only mortality reductions are considered. When health improvements are included the magnitude of increasing returns for ageing-related diseases are magnified due to the complementarity between mortality and morbidity reductions.

Figure 3: Willingness to Pay for reductions in disease cluster



Our baseline specification abstracts from health–productivity links, so our results do not rely on improvements in health increasing labour productivity. The estimated gains arise solely from welfare improvements associated with longer and healthier lives, not from higher wages. Incorporating productivity effects would therefore very likely reinforce our conclusions.

4 Increasing returns to tackling ageing

In this section we examine the causes of these increasing returns to tackling ageing-related diseases and why they are not present for other disease clusters. Firstly, a key mechanism is an extensive margin effect that operates through the mathematical properties of reducing mortality at older ages, which we discuss in Section 4.1. Secondly, in addition this longevity channel there is also a second mechanism operating through complementarities between mortality and morbidity, which is discussed in Section 4.2. This works through both a mechanical complementarity where agents value health improvements more if they will be alive to enjoy them, as well as an economic channel. As the burden of ageing-related diseases decline, there are not just more years at older ages but years spent in better health. This encourages agents to substitute consumption to later years, further raising the gains from tackling ageing-related diseases.

Importantly, these amplifying mechanisms dominate several forces that would otherwise generate diminishing returns. In our model specification we abstract from life cycle factors that would encourage individuals to invest in later life human capital in response to longer lives (Strulik, 2022; Scott, 2021)) and so boost productivity. We also do not include any labour productivity effect of health.

4.1 Increasing returns to life expectancy from later life mortality

We can see from the red line of Figure 3 that there are strongly increasing returns to reducing ageing related diseases even if only mortality improvements are considered (so health profiles do not change at all). The reason for this is that there are strong increasing returns to *life expectancy* of reducing mortality from ageing related diseases. In other words, the more we reduce the prevalence of ageing-related diseases, the more life years we get from further reductions. These mortality effects work through integral over $S(a,t)$ in Equation 3, which if we hold all over variables constant, is simply as linear transformation of life expectancy. It is thus convenient to see this increasing returns channel through the effect of mortality at a given age on life expectancy at birth.

$$LE(0) = \int_0^\infty S(a)da = \int_0^\infty \exp\left(-\int_0^a \mu(x)dx\right)da \tag{7}$$

Wrycza and Baudisch (2012) find that changes in life expectancy in response to a change in mortality ϵ can be calculated by summing up the changes in mortality over all ages, weighted by the remaining person-years of expected life at each age:

$$\frac{dLE(0)}{d\epsilon_i} = -\int_0^\infty \frac{\partial\mu(a)}{\partial\epsilon_i} LE(a)S(a)da \tag{8}$$

This has three components:

1. Mortality effect, $\frac{\partial\mu(a)}{\partial\epsilon_i}$. This is straightforward - if ϵ_i has a bigger effect on mortality it has a bigger effect on life expectancy.

2. Remaining Life Expectancy effect, $LE(a)$. This is forward looking and reflects mortality rates after a, so that reducing mortality is more valuable at ages where there is a lot of life ahead.

3. Survival effect, $S(a)$. This is backward looking and reflects mortality rates before age a, so that reducing mortality is more valuable at ages where the newborn is likely to still be alive.

Equation 8 is the first order effect, so for a fixed absolute change in mortality it will be greater the earlier in life the gains are as $LE(a)$ and $S(a)$ are higher for younger ages. This makes the fact that ageing-related disease have a first order effect comparable and even greater than infant diseases striking. At older ages, the $\frac{\partial\mu(a)}{\partial\epsilon_i}$ term is large for age-related diseases and is multiplied by an $LE(a)S(a)$ term that is getting larger. It is this that drives our increasing returns/virtuous circle result.

To see this consider the second derivative :

$$\frac{d^2LE(0)}{d\epsilon_i^2} = -\int_0^\infty \left[\frac{\partial^2\mu(a)}{\partial\epsilon_i^2} LE(a)S(a) + \frac{\partial\mu(a)}{\partial\epsilon_i} S(a)\frac{\partial LE(a)}{\partial\epsilon_i} + \frac{\partial\mu(a)}{\partial\epsilon_i} LE(a)\frac{\partial S(a)}{\partial\epsilon_i}\right]da \tag{9}$$

The more positive this second derivative is, the stronger the increasing returns in ϵ_i are. To make sense of this expression, note that $\frac{\partial^2\mu(a)}{\partial\epsilon_i^2} = 0$ because we define disease prevalence reduction in percentage point terms relative to the current burden. Then, noting that $\frac{\partial y}{\partial x} = y\frac{\partial \log y}{\partial x}$, we can rewrite this as :

$$\frac{d^2LE(0)}{d\epsilon_i^2} = -\int_0^\infty \frac{\partial\mu(a)}{\partial\epsilon_i} S(a)LE(a)\left[\frac{\partial \log LE(a)}{\partial\epsilon_i} + \frac{\partial \log S(a)}{\partial\epsilon_i}\right]da \tag{10}$$

This gives us an intuitive explanation for why eradicating ageing-related diseases has increasing returns for life expectancy and therefore to WTP for further reductions. At the ages where they have the highest mortality effect, ageing-related diseases have a greater *proportional* effect on both remaining life expectancy ($LE(a)$) and survival until that age ($S(a)$) than is the case for other diseases.[3] Infant diseases provide a useful contrast here - infant diseases are proportionally a very small part of $LE(a)$ and $S(a)$ at the ages where they have their largest mortality effect. This in turn is a direct result of the fact that ageing-related diseases increase with age - this makes the mortality effect always largest where the proportional effect on LE and $S(a)$ are greatest. For every other disease cluster, as greater progress is made these terms reduce in importance. Because ageing-related diseases are defined by an upward sloping mortality curve the more progress is made in tackling ageing-related disease a new window is opened up where large proportional gains in $LE(a)$ and $S(a)$ are feasible.

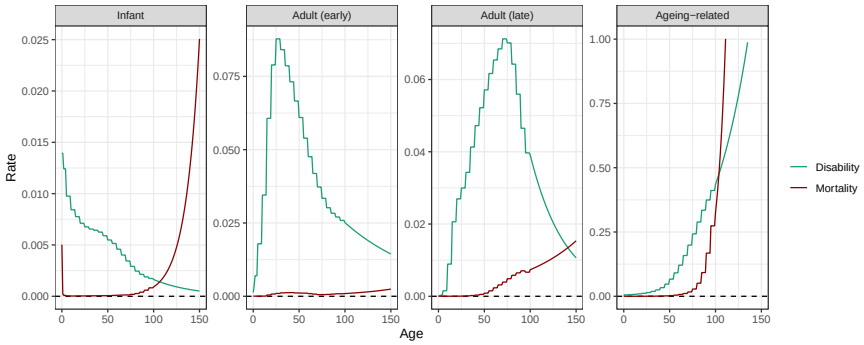
[3]Other clusters do also have a slightly positive second derivative and so do experience some form of increasing returns. However, because the derivative is very close to zero and so the increasing returns to life expectancy are very weak, unlike for ageing-related diseases

4.2 Increasing returns through the mortality and morbidity complementarity

As shown by the shaded grey area in Figure 3, around half of the increasing returns to tackling ageing-related disease are driven by a complementarity between mortality and morbidity. It is driven by two channels. First, improvements in health quality are more valuable when individuals live long enough to experience them. Second, good health enhances the utility derived from consumption and leisure so individuals optimally reallocate consumption toward later ages when health improves, making the higher chances of survival in those later ages more valuable. This consumption-smoothing response magnifies the welfare impact of longevity gains and is central to the increasing returns observed for ageing-related disease reductions.

As with the pure mortality effect, this complementarity is much stronger for ageing-related diseases than the other disease categories. This is because ΔS and ΔH are much more positively correlated for ageing related disease that for other disease clusters, as shown in Figure 4 which compares the mortality and disability rates across the lifecycle for each disease cluster.

Figure 4: Disability and mortality rates by disease cluster



This tells us that ageing-related diseases affect mortality and health at the same point in the lifecycle, while other disease clusters typically do not. In the US 2023 data, for infant diseases the correlation of the health and mortality curves is 0.05, for early adult it is -0.008, for late adult it is -0.06, while for ageing related diseases it is 0.43.

4.2.1 Health is more valuable in years with a high survival probability

Improvements in health are more valuable when individuals are more likely to live long enough to experience them, while extensions of life are more valuable when those additional years are lived in good health. This can be seen in the second term on the right hand side of Equation 3: $S(a,t)\frac{\Delta H(t)}{H(t)}\frac{u(c(t),\ell(t))}{u_c(c(t),\ell(t))}$. If we hold consumption and leisure paths fixed, then $v(t)$, $c(t)$ and $\ell(t)$ do not vary (we address the fact that they do vary in Section 4.2.2 below). In this case, we see that the impact of a health improvement in year t, $\Delta H(t)$, still depends on the agents' probability of surviving until that year, $S(a,t)$. This gives a complementarity that as disease reduction increases $S(a,t)$ any accompanying $H(t)$ gains will be valued more highly.

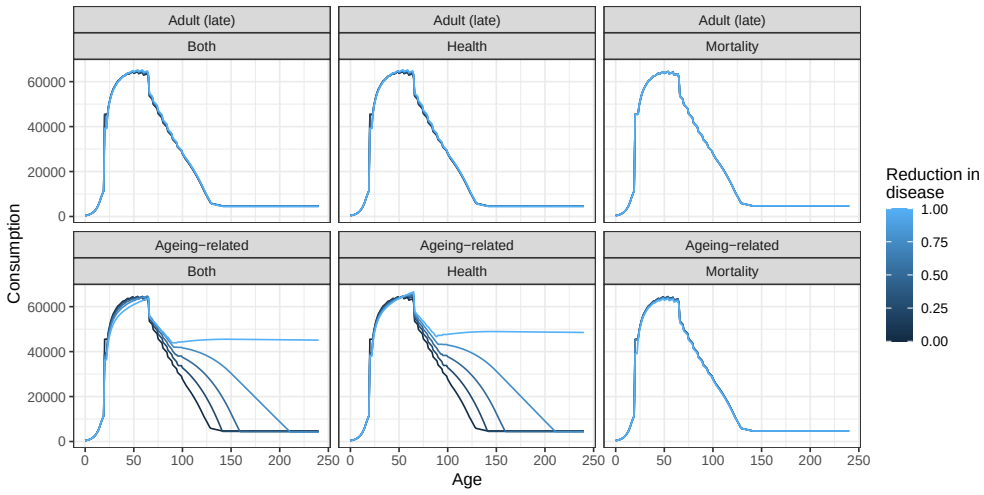
There is an additional potential channel through which this complimentarity does not work. While agents are certainly better off in years in which they are healthier, the basic assumptions of the Murphy and Topel (2006) model mean that it willingness to pay does not mechanically increase for a life year in which the agent is healthier. This is because better health increases the marginal utility of wealth and so this cancels out the effect of the life year being more valuable. Agents value a healthier year more, but they also value wealth more in a year in which they are healthier. We can see this in the first term on the right hand side of Equation 3: $v(t)\Delta S(a,t)$. The $v(t)$ term, which defines the monetary value of a life year, does not include a health term as can be seen from Equation 4.

4.2.2 Marginal utility of consumption and leisure are higher in good health

This effect is driven by the fact that health acts as a multiplier on $u()$ and so as health improves, people shift consumption to their newly healthy years. This increasing consumption because of better health leads to a higher $v(t)$ in the affected years. We can see how this will lead to a complementarity with mortality improvements in the $v(t)\Delta S(a,t)$ term in Equation 3 - a higher $v(t)$ of higher consumption will lead to a greater value being placed on survival probabilities corresponding to that year.[4]

As with the survival weighting on health gains described in the previous subsection, this channel is much stronger if diseases affect mortality and health substantially and at the same point in the lifecycle. This consumption reallocation effect is thus much stronger for ageing-related diseases than for the other clusters. We can see this illustrated in Figure 5 which compares the consumption paths as a disease cluster is reduced for late adult and ageing related diseases. From left to right, each panel shows how the consumption profile changes as (i) both mortality and health are improved, (ii) only health is improved, (iii) only mortality is improved. In the top three panels we see that there is very little change in consumption paths for late adult diseases. In the lower panels we see that if health is improved through reducing ageing-related disease, there are large increases in consumption at later ages. If just mortality is improved there is very little change even for ageing-related disease, emphasising that the changing consumption patterns are driven by improving health incentivising higher consumption.

Figure 5: Disability and Mortality contributions of each disease cluster over the life-cycle



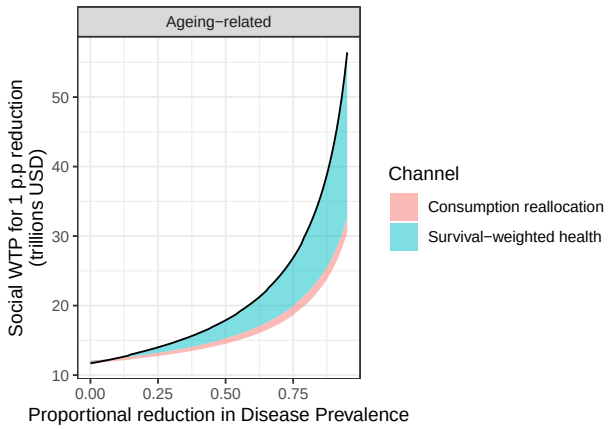
While leisure does also adjust, this effect is much smaller as the mortality and health gains mostly affect years in which the exogenously given wage rate is very low, so agents already choose not to work in those years.

4.2.3 Decomposing the complementarity

Figure 6 decomposes the complementarity into these two channels using the willingness to pay for improving both mortality and health, but when agents have the consumption and leisure paths they would if only mortality were improved. This isolates the effect of the consumption reallocation that is encouraged by better health at later ages. We see that the majority of the complementarity is driven by the survival rate weighting on health gains, but there is also a substantial role for the consumption reallocation channel.

[4]There will also be an affect on the second term through the $\frac{u(c(t),\ell(t))}{u_c(c(t),\ell(t))}$, but this is ambiguous and quantitatively much smaller.

Figure 6: Decomposing the complementarity



5 Implications and Conclusions

In the 20th century the U.S experienced substantial increases in life expectancy and improvements in health. In the 21st century, despite rising health expenditure, life expectancy gains have slowed and the years spent in poor health have increased. This paper explains these trends in terms of a rising importance of ageing-related diseases. It shows using a canonical economic welfare model that a focus on treating disease that led to improvements in life expectancy in the 20th century leads to diminishing returns. Reducing the disease burden from diseases that are most prominent in infant, early adult or later adult years has led to life expectancy over 70 years but further reductions lead to increasingly small gains in life expectancy. By contrast, reductions in ageing-related diseases lead to larger gains to life expectancy and due to a complementarity between morbidity and mortality larger gains in health capital. Crucially, tackling ageing-related diseases leads to an extensive margin effect that leads to more years in better health at older ages making further gains in reducing the impact of ageing related diseases all the more important. As life expectancy extends, the importance of tackling ageing related diseases becomes ever more important. The implications of our analysis for the U.S health system suggest a focus on maintaining health rather than tackling disease when it becomes prevalent, an emphasis on compressing morbidity rather than increasing life expectancy and a greater understanding of the biology of ageing.

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