International Gains to Achieving Healthy Longevity*

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Abstract

Utilising economic tools, we evaluate the gains from improving the relationship between biological and chronological age in dollar terms. We show that the gains to individuals are substantial because targeting aging exploits synergies between health and life expectancy and the complementarities across different diseases. Gains are boosted by improvements in life expectancy and a rising number of older people. We compute the value of slowing aging in a range of countries and estimate that increasing life expectancy by one year has an annual benefit of around 4-5 per cent of GDP. Augmenting GDP with these measures of health gains reveals the growing importance of achieving healthy longevity as a means of boosting welfare, with the need being particularly acute in the U.S.

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1 Introduction

The advent of the global pandemic in 2020 led to massive disruption for the world economy, with actions taken by individuals and governments to minimise the health impact of the pandemic leading to dramatic falls in GDP (Bonadio et al., 2020). Many lessons will be drawn from Covid-19 but central amongst them should be just how much we value our health.

Whilst attention has been focused on the Covid-19 pandemic, a greater threat to the world's health and economic future in the coming decades is the rising incidence of age-related diseases. With life expectancy gains increasingly driven by mortality improvements at older ages (Vaupel et al., 2021), more years are spent by individuals in the 'red zone' characterised by high levels of frailty and poorer health (Olshansky and Carnes, 2019). These trends are producing an increase in global deaths from non-communicable diseases (expected to rise by 66% between 2016 and 2040 (Foreman et al., 2018) and more years spent in poor health, lower productivity, and placing an increased burden on society.

Given these two facts, how much we value health and the rising burden of age-related diseases, it is no surprise that the benefits of achieving healthy longevity are estimated to be substantial. Using different economic methodologies, both Goldman et al. (2013) and Scott et al. (2021) calculate multi-trillion dollar benefits from improvements in slowing the rate at which we age.

Applying economic tools to evaluate longevity gains provides insights over and above simply arriving at a dollar value. As shown in this paper, these tools reveal the relative importance of extending life expectancy vs compressing morbidity (Fries, 1980), the relative merits of tackling single diseases versus the aging process itself, as well as revealing an important interplay between the dynamics of health and life expectancy. The tools also point to a virtuous circle whereby the longer and healthier we live, the more we value additional gains in healthy longevity. This leads to the conclusion that not only is targeting aging a key research priority today, but we are entering a new epidemiological transition (Olshansky and Ault, 1986) where improvements in how we age lead to greater interest in further gains.

The paper begins by outlining the economic tools used to evaluate health gains and applying them to issues of healthy longevity and the benefits of increased longevity versus compressing morbidity. It then shows why focusing on aging itself is important relative to targeting single diseases and evaluates the relative benefits of reversing rather than slowing aging. An explanation is provided as to why the importance of targeting aging has only recently emerged as a priority. The focus then shifts from the individual to the aggregate level by calculating the total value of improvements in aging for a number of high-income countries. This analysis places a dollar value on improvements in healthy longevity. When the measures are used in combination with GDP data to consider the welfare performance of a range of countries over recent decades, it shows how extending the healthy period of life and compressing morbidity is becoming ever more important and relevant.

2 Main text

2.1 Evaluating Gains to Health and Longevity

There are three broad approaches to assigning a dollar value to the gains arising from healthy longevity. The first is to calculate the impact in terms of current and future GDP growth, as

longer, healthier, lives lead to an increase in education, employment and productivity, and have the potential to generate an economic longevity dividend (Scott, 2021). The second is to estimate savings in terms of lower health costs and expenditures that arise from reductions in age-related diseases (Fries et al., 1993). The third places a monetary estimate (Viscusi, 2018) on how much individuals value health gains, independently of any impact on their income or expenditure.

Each of these approaches is important and provides an insight into a different question. The GDP calculations have appeal to Ministries of Finance, but they require economic models that incorporate shifts in healthy longevity and the various mechanisms through which this influences economic growth, e.g., delayed retirement, greater investments in health and education, influences on innovation, and so on. Successful application of this approach requires the development of a canonical model for the economics of longevity, which is currently absent (Scott, 2021).

The magnitude of potential health cost savings arising from extending healthy lifespan are clearly attractive to Ministries of Health. However, this focus on cost savings is restrictive from a welfare point of view as it rules out potentially highly valuable treatments. That is important given that both individuals and society are likely willing to spend more on reducing the incidence of age related diseases than they are on dealing with their implications. As stressed by Hall and Jones (2007) given how valuable health improvements are, the consequence of rising prosperity is an ever-higher proportion of income on health outcomes. With age related diseases increasingly the most important health challenge this points to rising medical costs as being acceptable in order to achieve healthy longevity.

This focus on measuring the welfare gains from health improvements is the basis of the third approach and is the one utilised in this paper. That is to use the Value of Statistical Life (VSL) framework (Viscusi, 1993) to derive a Willingness to Pay (WTP) measure for improvements in healthy longevity. These WTP measures place a dollar value on gains to health or life expectancy. Importantly, they are not based solely on considerations of how the gains impact the economy or an individual's earning potential, but instead capture the broad value individuals and society place on health. As Covid-19 shows, this is considerable. According to Greenstone and Nigam (2020), the VSL for the U.S. currently stands at $11.5 million, based on updated EPA figures for inflation and economic growth.

The VSL approach is related to attempts to measure the cost effectiveness of health expenditures by considering the cost in terms of Quality-Adjusted Life Years (QALY) of different treatments. For example, in the UK the National Institute for Health and Care Excellence (NICE) considers treatments that cost less than £30,000 per Quality-Adjusted Life Year (QALY) saved to be good value. With UK life expectancy currently being 83 years, the value of saving a life at birth becomes 83 x £30,000, or around £2.5million.

Murphy and Topel (2006) developed a VSL model based on an economic analysis of the life cycle. Given expectations about health and life expectancy, interest rates and wages, individuals decide how to structure their life in terms of work and leisure, consumption and savings. Changes in any of these variables lead to changes in lifetime economic decisions. For instance, the economic model shows how individuals respond to an increase in life expectancy by increasing labour supply and changing consumption and savings at different ages to support their longer life.

These responses matter as they lead to changes in the VSL, and it is these changes that enable

calculation of an individual's Willingness to Pay (WTP) for health improvements. The shifts in behaviour are also important in enabling a dynamic analysis of how the WTP adjusts in response to changes in health and life expectancy, which is key for understanding future trends around the value of healthy longevity.

The VSL depends on two features – the quantity and quality of life. The quantity of life is captured by life expectancy in the form of a survival function showing the probability of surviving to a given age. The quality of life is captured by three variables – health, consumption and leisure. As health and life expectancy change, individuals re-evaluate and adjust their life plans in terms of consumption, savings and work in order to finance longer lives and benefit from health changes. These changes contribute to shifts in the VSL.

This VSL framework can be used to evaluate the relative merits of living longer or achieving a compression of morbidity. In Scott et al. (2021) this is done by considering two scenarios – Struldbrugg and Dorian Gray. In the Struldbrugg scenario, life expectancy is increased by improvements in the survival function that lead to higher survival probabilities at each age. However, the assumption is that the relationship between health and age is unchanged, as with the life of the Struldbruggs on the island of Luggnag in Jonathan Swift's "Gulliver's Travels" who live forever but in ever-declining health.

The Dorian Gray scenario is the opposite.. In Oscar Wilde's novel "The Portrait of Dorian Gray", Gray strikes a bargain so that his portrait ages but his body does not, allowing him to remain youthful in appearance until he dies. This is the case where health improves at each age, but life expectancy remains unchanged (mortality is the same). In the limit, healthy life expectancy becomes the same as life expectancy and there is a full compression of morbidity.

Using these two scenarios, Scott et al. (2021) arrive at the following conclusions:

1. Gains to life expectancy are valuable under the Struldbrugg scenario, despite no improvements in health. A rise in life expectancy at birth from the current U.S. level of 78.9 to 79.9 years is estimated to be worth $118,000 to an individual at birth.

2. Increasing life expectancy without changing health suffers from diminishing returns, due to declining health and the extra work required to finance longer lives. The result is that a rise in life expectancy from 88.9 to 89.9 years is worth only $81,800.

3. More valuable is to raise healthy life expectancy, even in the absence of gains to life expectancy. Raising U.S. healthy life expectancy at birth from its current value of 68.9 years to 69.9 is worth an estimated $242,000.

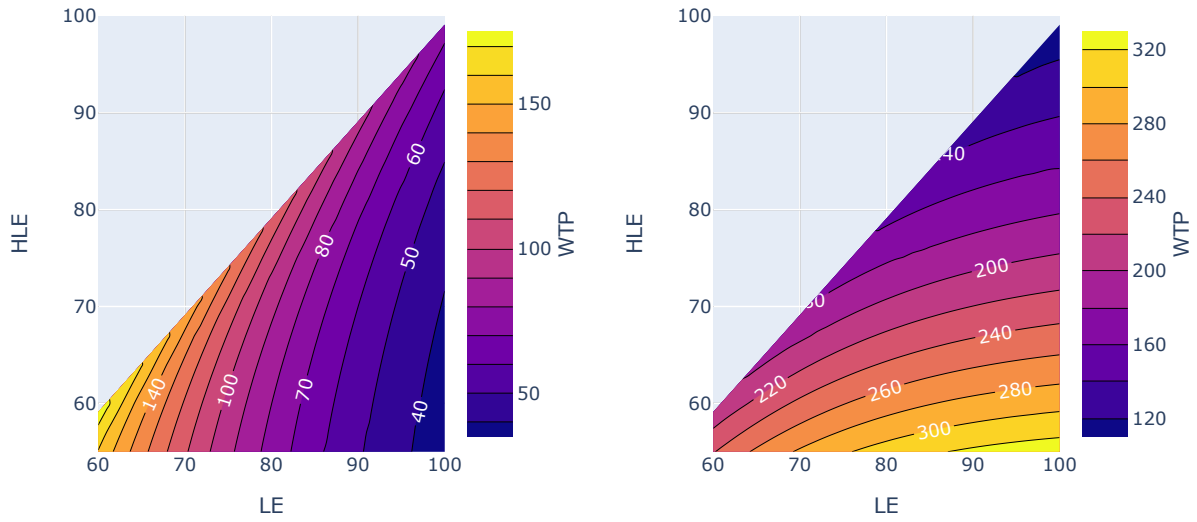
4. Gains from compressing morbidity diminish but remain high. In the U.S. it is currently more beneficial to achieve a full compression of morbidity than to increase life expectancy.

5. The gains to healthy longevity are largest at older ages because the older you are the more likely you are to benefit from health gains at older ages, the gains happen sooner for older people and so are discounted less, and better health in later life leads to a relative reallocation of consumption towards those years.

The logic behind these results can be seen in Figure 1. Figure 1a shows the value at birth of

achieving a one-year increase in life expectancy (LE) by reducing mortality, evaluated at different initial levels of life expectancy and healthy life expectancy (HLE). Figure 1b does the same but for one year increases in HLE achieved by improving health. These show that increases in HLE are more valuable than increases in LE at every point in the grid. They also show that there are diminishing returns to improvements that only affect either health or mortality. Above all, Figure 1 shows the complementarity between health and longevity. For any given level of LE, the higher is HLE the greater the gains from improvements in mortality. Similarly for any given level of HLE, the greater is longevity the greater the value of improvements in health. The complementarity between health and longevity is an important part of the value of targeting aging.

Figure 1: Willingness to pay for reducing mortality and improving health



(a) WTP in thousand US dollars for one extra year of life expectancy by improving mortality. Increases in LE are more valued for higher HLE.

(b) WTP in thousand US dollars for one extra year of *healthy* life expectancy by improving health. Increases in HLE are more valued for higher LE.

2.2 Targeting Biological Age

Both the Struldbrugg and Dorian Gray scenarios are based on changes in how we age. In Strudlbrugg the relationship between mortality rates and chronological age is improved, whilst in Dorian Gray it is the relationship between health and chronological age that changes.

A more profound possibility exists if mortality and morbidity are jointly related to an underlying concept of biological age. For example, it has been shown that broad measures of health such as frailty indices (Mitnitski et al., 2002) capture health and mortality risks better than chronological age (Rockwood et al., 2017). If frailty is driven by biological aging, then improvements in how we age could simultaneously shift both the survival and health functions. Doing so would boost life expectancy and healthy life expectancy in tandem, triggering the complementarities detailed above. Indeed, for laboratory animals or humans, gains in overall health due to the slowing of aging are almost always associated with an increase in lifespan (Olshansky et al., 2019; Campisi et al., 2019).

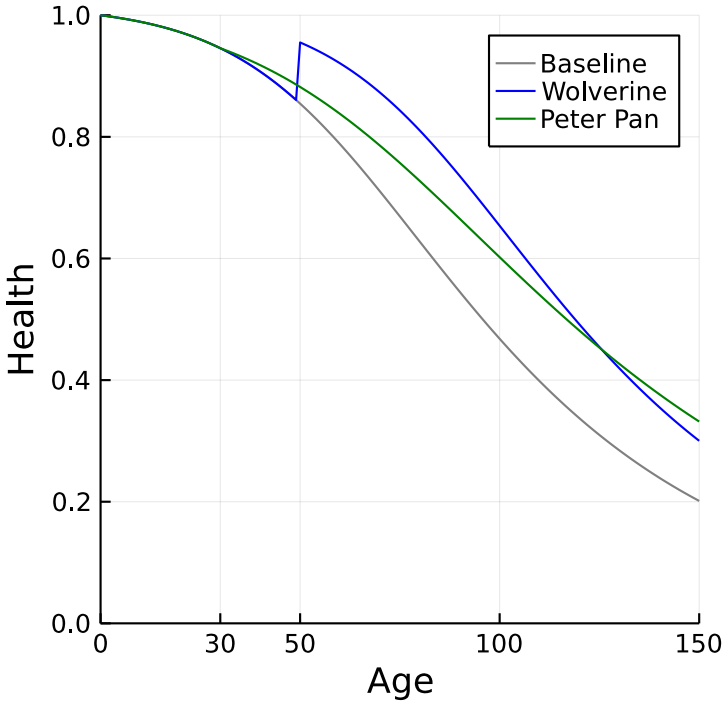
Scott et al. (2021) refer to the slowing down of biological age as the Peter Pan scenario, based on J.M. Barry's play about a boy who never grows up. In the extreme case, where biological age is constant regardless of chronological age, no aging occurs. The Peter Pan scenario leads to more valuable outcomes than either Dorian Gray or Struldbrugg because it exploits the complementarities shown in Figure 1.

The Peter Pan scenario illustrates two mechanisms through which targeting biological aging leads to more valuable outcomes than treatments focused on single specific diseases. The first is a simple aggregation effect. If biological age is the driver of multiple age-related diseases then targeting aging will lead to more valuable outcomes simply because it aggregates across numerous diseases. The second is through the elimination of competing risks. Reducing the incidence of, say, cancer leads to improvements in life expectancy and health, but the gains are limited by the existence of other age-specific diseases such as dementia, COPD, etc. The complementarity between health and life expectancy means the gains from eliminating cancer are greater if these other age-related diseases are also absent. The result is that reducing the joint incidence of age-related diseases is more valuable (by around 20-30%) than the sum of reducing the incidence of each disease separately (Scott et al., 2021).

The Peter Pan scenario involves slowing down biological aging. Another possibility is that the biological aging process is reversed. Recent discoveries point to aging being a result, at least in part, of a loss of information at the epigenetic (gene regulation) level, and to the existence of a back-up copy of this information that can be accessed when certain embryonic genes are turned on in adult tissues (Zhang et al., 2020). Scott et al. (2021) refer to this as the Wolverine scenario, based on the Marvel character of the same name who has the capacity to regenerate limbs and organs. Scott et al. (2021) compare the case of Peter Pan (a permanent slowdown in the rate of biological aging) to a one-time Wolverine treatment at age 50 years. Conditional on achieving the same improvement in life expectancy they show that the gains are broadly similar, although Peter Pan is slightly preferred to Wolverine.

Figure 2 shows why the Peter Pan and Wolverine scenarios are similar despite their different biological foundations. The impact of Peter Pan is to reduce the rate at which health declines with age (here assumed to start from age 30), hence the health function is higher at all ages relative to the baseline. By contrast, under Wolverine there is a reset of health to an earlier level (here assumed to occur at age 50). Peter Pan therefore leads to higher health for all ages past 30, whilst Wolverine only has a benefit for those aged 50 and above. Furthermore, Peter Pan is eventually higher than Wolverine at higher ages because Wolverine resets rather than slows the rate of aging. The net effect of these relative shifts is that the WTP for Peter Pan and Wolverine are broadly alike.

Figure 2: Comparing health effects of Peter Pan and Wolverine. In both cases life expectancy at birth is increased to 100 years, driven by slower biological aging from age 30 for Peter Pan and a one-off reversal in biological age at 50 for Wolverine.



This logic though is based on the assumption that Wolverine is a one-time intervention. Imagine instead if a Wolverine reset can be performed every year, indefinitely and without loss of efficacy. Whilst this may seem a radical extension, it is again worth stressing the similarities with Peter Pan. In fact, repeated Wolverine is isomorphic to Peter Pan. Consider the case where Wolverine is repeated every 12 months and produces a reversal in biological age of 3 months. That is exactly equivalent to Peter Pan where the rate of aging is slowed down by 25%, i.e., every 12 months biological age only increases by 9 months.[1] At least within our framework, Peter Pan and repeated Wolverine are the same and their merits then depend on the relative biological feasibility and costs.

Table 1 shows the WTP for repeated annual applications of Wolverine treatments in which biological age is reversed by 3, 6, 9 or 12 months each year, starting at age 30, 50 or 70. The WTP for these interventions is substantial because they lead to major increases in both life expectancy and healthy life expectancy.[2]

[1] Oeppen and Vaupel (2002) document a historical two to three year improvement in best practice life expectancy every decade. This is akin to a 25% reset of biological age each year in terms of its impact on mortality, i.e., biological age in terms of impact on mortality rises only 9 months each calendar year.

[2] Our results are based on a fixed schedule for wages that declines with age, calibrated to the empirical evidence in Casanova (2012). Given the large changes in life expectancy of Table 1, it is likely that changes in lifelong learning, health and career decisions would lead to significant variations in wages especially at older ages, all of which would lead to substantial changes in the WTP (and probably much higher estimates).

Table 1: Effects of repeated Wolverine (reversing aging)

Starting Age	Annual Reset	Life Expectancy	Healthy Life Expectancy	WTP at birth ($000s)
Baseline		78.9	68.7	
30	3 months	91.0	79.0	1,290
30	6 months	113.0	98.0	2,996
30	9 months	167.9	146.4	5,205
30	12 months	1,782.6	1,686.9	7,161
50	3 months	85.0	73.5	564
50	6 months	95.3	81.7	1,362
50	9 months	118.1	100.5	2,585
50	12 months	307.3	267.5	4,425
70	3 months	80.5	69.8	117
70	6 months	82.9	71.5	281
70	9 months	87.0	74.5	532
70	12 months	99.3	83.9	999

Consider the case of repeated annual Wolverine treatments that starts at age 50 and each reverse aging by 12 months. The impact of this is that every year after age 50 is characterised by the same mortality rate and health as at age 50, regardless of advancing chronological age. The result is a major increase in both life expectancy (now 307 years) and healthy life expectancy (268 years). Not surprisingly given these numbers, the WTP at birth for such an intervention is enormous ($4.425mn).

The WTP is higher if the reset locks in the mortality and health of a 30 year old ($7.16mn), and lower if the lock in occurs at the mortality and health of a 70 year old ($1mn). It is worth noting the very extreme life expectancy that locking in at the mortality of a 30 year old produces - 1,783 years. At this level of life expectancy our model is being pushed into uncomfortable terrain where its applicability is questionable. For instance, discounting benefits that occur in 1,700 years' time produces very small numbers. Similarly, our model is based on a life cycle model that would need seriously different assumptions to plausibly model a 2,000 year life.

2.3 A New Epidemiological Transition

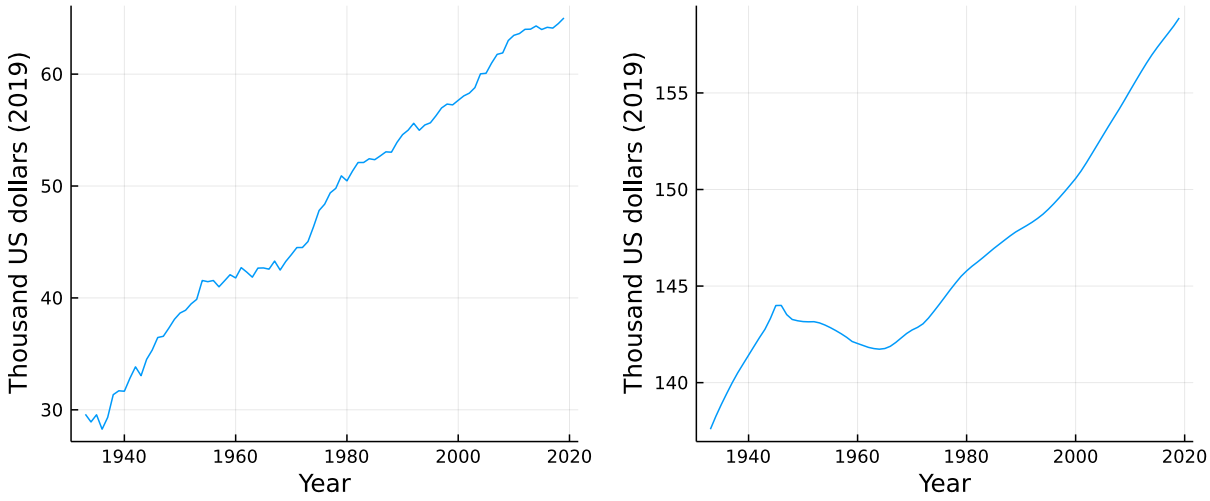
The above analysis shows treatments that slow down or reverse biological aging are very valuable, as doing so exploits a number of complementarities between health and life expectancy. However, the importance of exploiting these synergies has not always been so great. That is changing for two reasons.

The first is relatively simple. The benefits of targeting aging depend on the probability of experiencing age-related diseases. In 1933 a new-born in the US had a 21% chance of reaching 80 years of age. Assuming no changes in future mortality, a new-born in 2019 had a 59% chance of doing so. This shift in probability leads to a significant increase in the WTP for tackling aging. That is because the gains from reducing age-related diseases depend on the probability of experiencing them.

The value of improvements in how we age has therefore increased as life expectancy has increased.

This is shown in Figure 3a, which plots the WTP at birth for a 10% "Dorian Gray" slowdown in the rate of biological aging (assumed only to impact health and not mortality, and starting at age 50) but evaluated using mortality rates in the US in each year between 1933 and 2020. The increased probability since 1933 of the young becoming old leads to a substantial increase in the WTP for improvements in aging. Since 1941 the value has doubled, and has increased by 13% even compared with 20 years ago.

Figure 3: The effect of changing mortality and population structure on the value of longevity



(a) WTP at birth for a 10% slowdown in aging with historical life expectancy and survival rates

(b) Average individual WTP for a 10% slowdown in aging with historical population structure

The second reason why the WTP for healthy longevity gains increases is due to changes in population size and structure. Improvements in mortality mean fewer people dying and a larger population, which directly increases the gains to society of any health improvements. In addition, improvements in longevity mean not just more people but more older people. As the old value gains from increased longevity more than the young, this compositional effect boosts the social gains from targeting aging. This is shown in Figure 3b, which uses the population age structure between 1933 and 2020 and the WTP at different ages to construct an estimate of the social gains from healthy aging. These have increased as the proportion of the population aged over 50 has increased.

These two factors (longer lives, more old people) together lead to a rising value for targeting aging and point to the emergence of a new epidemiological transition (Olshansky and Ault, 1986) focused on tackling age-related diseases.

2.4 International Gains

Scott et al. (2021) use calculations of individual WTP for improvements in healthy longevity and population projections for the U.S to calculate aggregate WTP numbers of economic value at a national level. In this section we extend the analysis to a range of other high income countries.[3] To do so, we follow Viscusi and Masterman (2017) and calculate the VSL for country i using the

[3]Whilst we can in theory perform the same calculations for low and middle income countries, a number of assumptions and calibrations of our model suggest restricting our focus in this way.

following equation (and for 2020 GDP):[4]

$$VSL_i = VSL_{US}\left(\frac{Y_i}{Y_{US}}\right)^{\eta} \tag{1}$$

where η is the elasticity of the VSL with respect to income, which following Viscusi and Masterman (2017) is set equal to 1. We also need to calibrate our survival and health functions for different countries. We do this by adjusting the lifespan in our mortality functions so that the survival curve matches the life expectancy for each country and the health function matches healthy life expectancy. We then use the latest UN (2019) data on the size and age structure of the population to calculate the aggregate value of a slowdown in aging (as in Peter Pan) that leads to a one year increase in life expectancy from its current base (phased in over a ten year period).

Table 2: International Gains to Targeting Aging

	Life Expectancy	Healthy Life Expectancy	Pop. (mns)	GDP p.c. ($000s)	WTP Current ($trn)	WTP Future Gen ($trn)	WTP Total ($trn)
Australia	83	70.9	25.5	47.0	2.2	0.7	2.9
Canada	82.2	71.3	37.74	43.4	3.1	0.9	4
France	82.5	72.1	65.27	40.9	5	1.2	6.2
Germany	81.7	70.9	83.78	47.1	7.6	1.6	9.2
Israel	82.6	72.4	8.66	38.6	0.6	0.3	0.9
Italy	83.0	71.9	60.46	35.1	4.1	0.6	4.7
Japan	84.3	74.1	126.48	40.4	9.5	1.3	10.8
Netherlands	81.8	71.4	17.13	52.4	1.7	0.4	2.1
New Zealand	82	70.2	4.82	40.6	0.4	0.1	0.5
Spain	83.2	72.1	46.75	34.2	3.1	0.5	3.6
Sweden	82.4	71.9	10.1	50.0	1.0	0.3	1.3
UK	81.4	70.1	67.89	39.1	5.1	1.4	6.5
USA	78.5	66.1	331	58.2	38.4	12.5	50.9

The aggregate WTP for all countries (shown in Table 2) is sizeable and between 4% and 5% of GDP on an annual basis (assuming 2% interest rates). The precise value varies across countries depending upon GDP per capita (the higher is GDP, the higher the VSL), the size and structure of the population (the more people and the more older people the higher the aggregate WTP), and also the starting level of life expectancy and healthy life expectancy (the lower is either the more valuable are gains to healthy life expectancy). The same results that Scott et al. (2021) found for the U.S. hold here – the value of slowing aging and supporting healthy longevity is enormous. Health matters and the most important health issues for aging populations relate to age-related diseases.

2.5 Assessing Performance

The VSL methodology can be used not just to construct dollar estimates for hypothetical gains in healthy longevity but also to value actual gains achieved in the past (see Murphy and Topel (2006) Table 3). Combining the dollar value of these health gains with the income generated by the economy (in other words GDP) gives a broad measure of welfare.

[4]The numbers for the US are based on the most recent data and a different population series, so are not directly comparable with Scott et al. (2021).

Table 3 shows the performance of this broad measure of welfare for various countries since 1990, in terms of the separate contributions of GDP per capita and the dollar value of health improvements and a combined aggregate measure.[5]

Table 3: Economic Value of gains to GDP and health 1990-2018

	Australia	Canada	France	Germany	Israel	Italy	Japan	Nether lands	New Zealand	Spain	Sweden	United Kingdom	United States
	GDP per capita												
1990-1999	39.7	32.3	30.3	31.5	25.7	29.2	29.5	34.1	27.7	20.4	35.0	33.5	41.9
2000-2009	50.4	38.5	35.6	35.8	28.6	32.9	31.9	42.6	34.8	25.5	44.9	41.6	51.6
2010-2018	57.8	44.0	37.6	40.4	34.8	30.9	34.2	45.8	40.1	26.0	50.7	44.5	56.4
	WTP per capita												
1990-1999	25.4	5.7	14.9	22.0	6.6	19.8	17.0	8.7	22.2	12.1	16.4	16.1	14.3
2000-2009	26.2	19.2	21.8	17.9	19.2	21.8	15.7	30.1	24.5	15.8	20.6	29.6	16.8
2010-2018	10.4	0.8	11.1	4.0	10.6	7.6	12.1	3.3	2.1	5.6	11.6	1.7	-14.2
	GDP + WTP per capita												
1990-1999	65.2	38.0	45.2	53.5	32.4	49.0	46.4	42.8	50.0	32.6	51.4	49.7	56.1
2000-2009	76.6	57.7	57.5	53.7	47.8	54.6	47.6	72.7	59.3	41.3	65.5	71.2	68.4
2010-2018	68.2	44.7	48.7	44.4	45.4	38.5	46.2	49.1	42.3	31.6	62.2	46.2	42.2
	Share of Health Capital: WTP/(WTP + GDP)												
1990-1999	0.39	0.15	0.33	0.41	0.20	0.40	0.37	0.20	0.44	0.37	0.32	0.33	0.25
2000-2009	0.34	0.33	0.38	0.33	0.40	0.40	0.33	0.41	0.41	0.38	0.31	0.42	0.25
2010-2018	0.15	0.02	0.23	0.09	0.23	0.20	0.26	0.07	0.05	0.18	0.19	0.04	-0.34

GDP per capita has generally increased for all countries, although the rate of increase slowed in the wake of the Global Financial Crisis (2007-2009). An even more marked slowdown is apparent in the aggregate WTP for health and longevity gains. For every country except Israel, the monetary value of health gains achieved over the most recent period are the lowest since 1990. The performance of the U.S. is especially striking, with the aggregate WTP being negative. In other words, there has been an overall deterioration in health and life expectancy that has lowered welfare. The US ranks first in 1990 and second in 2018 amongst these 13 countries in terms of GDP but based on the combined index the US sees its ranking fall to 11th. Whilst the U.S. is a dramatic example, Table 3 shows that there has been a substantial reduction in the value of health gains achieved in high income countries in recent years.

Given the health challenges in these nations increasingly concern age-related diseases, the combined index is another way of understanding the main conclusion of this paper: there are substantial welfare gains to improving how we age. According to Table 3, the welfare gains from current health improvements are slowing, both in absolute terms and also relative to the size of the economy. Whilst there is much focus on the negative impact to countries from slower GDP growth and secular stagnation, Table 3 points to the equal if not overriding importance of improving health and life expectancy. Given current population structures and survival curves, there must be a focus on targeting aging itself.

3 Concluding Remarks

There are few things that matter to society as much as health. Given increases in life expectancy and shifts in the age structure of the population, it is now a priority to guarantee that we age well,

[5]Data on health and mortality is taken from Global Burden of Disease data, with health measured using the proportion of years lost to disease in each age bracket.

on both an individual and national level. Evaluations with economic tools show that the dollar value of improvements in healthy longevity run into multiple trillions of dollars at a country and global level. Despite the importance of achieving such healthy longevity, current approaches to increasing health and longevity are not working. Our estimates point to deteriorating performance in generating health gains in high income countries, both in absolute terms and relative to the size of economic gains. As populations age, governments need to set health and life expectancy as a policy goal and search for instruments that achieve healthy longevity gains. As part of this approach a relative shift in focus in medical research and drug development towards targeting the ageing process rather than specific single diseases seems warranted given the potential value and current diminishing success in achieving healthy longevity.

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A Model

The life-cycle model used is based on that of Murphy and Topel (2006), with parameters calibrated as in Scott et al. (2021). Both mortality and health are based on frailty that increases with age a:

$$F(a) = e^{\delta a - T}. \tag{2}$$

Mortality is defined as a Gompertz function:

$$\mu(a) = M_1 F(a)^{\gamma}. \tag{3}$$

The survival rate $S(a,t)$ then gives the probability of an individual of age a surviving to time t. Health is based on the ratio of disability at birth to current disability:

$$H(a) = \left(\frac{D_0 + D_1 F(0)^{\psi}}{D_0 + D_1 F(a)^{\psi}}\right)^{\alpha} \tag{4}$$

Agents choose their consumption and leisure over the life cycle to maximise utility subject to a standard budget constraint.

$$\int_a^{\infty} H(t) u(c(t), l(t)) S(a,t) e^{-\rho(t-a)}, \tag{5}$$

where instantaneous utility u has a CES form.

$$u(z) = \frac{z^{1-1/\sigma} - z_0^{1-1/\sigma}}{1-1/\sigma} \quad , \quad z = \left(\phi c^{1-1/\eta} + (1-\phi) l^{1-1/\eta}\right)^{\eta/(\eta-1)} . \tag{6}$$

Parameters are calibrated to match the US economy as in Scott et al. (2021). We use analytic expressions based on Murphy and Topel (2006) to calculate WTP for hypothetical changes in health and survival rates:

$$WTP(a) = \int_a^\infty \left[v(t) \Delta S(a,t) dt + \frac{\Delta H(t)}{H(t)} \frac{u(c(t), l(t))}{u_c(c(t), l(t))} \right] dt \tag{7}$$

where $v(t)$ is the value of a life year at age t. Social WTP is then found by weighting the WTP at each age a by the total population in that age bracket.

The extra year of life expectancy from improving mortality in Figure 1a is generated by changing M_1 in the mortality function. The extra year of healthy life expectancy from improving health in Figure 1b is generated by changing D_1 in the health equation. The "Peter Pan" exercises work through changing δ and the "Wolverine" exercises through resetting a to a previous level of health and mortality.

B Data

Historical mortality and population structure data for the US used in Figure 3 are taken from the Human Mortality Database.[6] In Figure 3a, we use historical survival rates but otherwise use the baseline calibrations, and evaluate WTP at birth for a 10% slowdown in aging with respect to health starting at age 50. In Figure 3b, we use the calculated WTP for the same change using the baseline calibration and compute the average WTP across society using the historical population structures.

For the international comparison of social WTP shown in Table 2 we use our baseline model but calibrate T in order to set life expectancy and α to set healthy life expectancy according to data from the World Health Organisation.[7]. We then scale the wage distribution to set the VSL according to GDP data from the World Bank.[8] Finally, we use current population data and future fertility projections from the UN World Population Prospects 2019.[9] We compute the WTP for an extra year of life expectancy by slowing down aging through the δ parameter, phased in linearly over 10 years.

To assess international performance, we use mortality rates and years lost to disease from the Global Burden of Disease dataset[10] to compute survival and health curves for each country over time. The VSL for each country is calculated using the World Bank GDP data mentioned above, and the wage distribution is scaled accordingly. In each year, we calculate the WTP for the health and survival curves of the following year.

[6] www.mortality.org
[7] https://apps.who.int/gho/data
[8] https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
[9] https://population.un.org/wpp/Download/Standard/Population/
[10] http://ghdx.healthdata.org/gbd-2019