The Value of Health and Longevity

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Abstract

We develop an economic framework for valuing improvements to health and life expectancy, based on individuals' willingness to pay. We then apply the framework to past and prospective reductions in mortality risks, both overall and for specific life-threatening diseases. We calculate (i) the social values of increased longevity for men and women over the 20th century; (ii) the social value of progress against various diseases after 1970; and (iii) the social value of potential future progress against various major categories of disease. The historical gains from increased longevity have been enormous. Over the 20th century, cumulative gains in life expectancy were worth over $1.2 million *per person* for both men and women. Between 1970 and 2000 increased longevity added about $3.2 trillion per year to national wealth, an uncounted value equal to about half of average annual GDP over the period. Reduced mortality from heart disease alone has increased the value of life by about $1.5 trillion per year. The potential gains from future innovations in health care are also extremely large. Even a modest 1 percent reduction in cancer mortality would be worth nearly $500 billion.

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I. Introduction

During the 20th century, life expectancy at birth for a representative American increased by roughly 30 years. In 1900, nearly 18 percent of males born in the United States died before their first birthday – today, it isn't until *age 62* that cumulative mortality reaches 18 percent.[1] As we demonstrate below, this remarkable increase in longevity reflects progress against a variety of afflictions and diseases, driving reductions in mortality at all ages. It illustrates a substantial, but unmeasured, increase in social welfare due to improvements in health.

This paper develops and applies an economic framework for valuing improvements in health and longevity, based on individuals' willingness to pay. We use our framework to estimate the economic gains from declining mortality in the United States over the 20th century, and to value the prospective gains that could be obtained from further progress against major diseases. We find that these values are enormous. Gains in life expectancy over the century were worth over $1.2 million per person to the current population. From 1970 to 2000 gains in life expectancy added about $3.2 trillion *per year* to national wealth, with half of these gains due to progress against heart disease alone. Looking ahead, we estimate that even modest progress against major diseases would be extremely valuable. For example, a permanent 1 percent reduction in mortality from cancer has a present value to current and future generations of Americans of nearly $500 billion, while a cure (if one is feasible) would be worth about $50 *trillion.*

[1] Death rates by age are recorded in *Vital Statistics of the United States.* Other developed countries show similar progress over the century. Longer term data are scant, but suggest that progress accelerated up until about 1950. For example, Swedish data since 1751 show an increase in life expectancy of 6 years between

Our analysis of the values of health improvements is founded on individuals' maximization of lifetime expected utility. We distinguish two types of health improvements – those that extend life by reducing mortality, and those that raise the quality of life. Life extension is valued because utility from goods and leisure accrues over a longer period, and improvements in the quality of life raise utility from given amounts of goods and leisure. This framework delivers precise expressions for the economic value of a life-year, for the value of remaining life, and for changes in these values when health improves. We show that the social value of improvements in health is greater: (a) the larger is the population, (b) the higher are average lifetime incomes, (c) the greater is the existing level of health, and (d) the closer are the ages of the population to the age of onset of disease. These factors point to an increasing valuation of health improvements over the past several decades and into the future. As the U.S. population grows, as lifetime incomes grow, as health levels improve and as the baby-boom generation approaches the primary ages of disease-related death, the social value of improvements in health will continue to rise.

We also show that improvements in health tend to be complementary; for example, improvements in life expectancy (from any source) raise willingness to pay for further health improvements by increasing the value of remaining life. This means that advances against one disease, say heart disease, raise the value of progress against other age-related ailments such as cancer or Alzheimer's. This is of significant empirical relevance, as it implies that the well-documented historical progress against heart disease, for which mortality has fallen by roughly 30 percent since 1970, has increased the value of further

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1800 and 1850, 9 years between 1850 and 1900, 17 years between 1900 and 1950, and 9 years between 1950 and 2000 (*Statistics Sweden, Program for Population Statistics)*.

progress against other afflictions. We find that reductions in mortality since 1970 have raised the value of further health progress by about 20 percent.

An analysis of the social value of improvements in health is a first step toward evaluating the social returns to medical research and innovations. Improvements in health and longevity are partially determined by society's stock of medical knowledge, for which basic medical research is a key input. The U.S. invests over $50 billion annually in medical research, of which about 40 percent is federally funded, accounting for 25 percent of government research and development outlays. [2] The $27 billion federal expenditure for health related research in FY 2003, the vast majority of which is for the National Institutes of Health, represented a real dollar doubling over 1993 outlays. Are these expenditures warranted? Our analysis suggests that the returns to basic research may be quite large, so that even greater expenditures may be worthwhile. By way of example, take our estimate that a 1 percent reduction in cancer mortality would be worth about $500 billion. Then a "war on cancer" that would spend an additional $100 billion (over some period) on cancer research and treatment would be worthwhile if it has a 1-in-5 chance of reducing mortality by 1 percent, and a 4-in-5 chance of doing nothing at all.

Against these potential benefits of improving health one must weigh the costs of implementing new medical technologies. Our analysis highlights some of the important economic issues surrounding the valuation of improvements in health, health research and the growth in health expenditures. Many of these issues have significant policy implications. For example, the annuitization of many public and private retirement benefits

[2] The distribution of health R&D expenditure is reported by the National Institutes of Health. See http://www.cdc.gov/nchs/products/pubs/pubd/hus/tables/2001/01hus126.pdf. Pharmaceutical industry R&D expenditures are reported in www.phrma.org/publications/publications/profile02/chapter2.pdf. Government

(Social Security, private pensions, Medicare and private medical coverage) and the prevalence of third party payers increase incentives to spend on medical care, even when benefits are far smaller than costs. These distortions also skew investments in research away from cost-decreasing improvements in technology, as the demand for care is artificially price insensitive. This creates "second-best" considerations in valuing medical advances: innovations that would otherwise be welfare improving may be socially wasteful because *ex-post* utilization decisions are distorted. In the presence of such distortions, we must take account of the induced effect that medical advances have on expenditures when evaluating the social returns to improvements in technology. Our methodology does this, and we provide evidence on the value of improving health relative to increased health care expenditures.

The paper is organized as follows. Section II provides some empirical foundation for the analysis that follows, documenting the increase in longevity, and its sources, that occurred has occurred in the U.S. Section III develops our economic model for valuing improvements in health and life expectancy, and calibrates willingness to pay for health improvements. Section IV contains the empirical application of our methods, estimating the economic gains associated with the improvements in life expectancy over the 20th century, with particular focus on the post-1970 period. We also estimate the potential gains to future progress against major categories of disease. Section V discusses implications for the social value of investments in medical research, and Section VI concludes.

II. The Setting: Long-Term Evidence of Improvements in Health

expenditures for health R&D are reported by the National Science Foundation; see www.nsf.gov/sbe/srs/nsf02330/historic.htm

Figure 1 shows life expectancy at birth and age 50 in the United States since 1900. These and other estimates that follow are based on cross sectional age-specific death rates at each date, so (when health is improving) they will underestimate life expectancy for a given birth cohort. The figure shows that life expectancy over the century increased by slightly over 30 years. Progress during the first half of the century was rapid and evidently concentrated at younger ages – life expectancy conditional on reaching age 50 grew only slightly. In 1900, about 18 percent of males died before their *first* birthday. By 1950 it took 5*2 years* for cumulative male mortality to reach 18 percent, and with current mortality rates it would take 62 years. Progress slowed between 1950 and 1970, especially for men, but the upward trend in life expectancy began again after 1970. Late century gains were especially prominent for older individuals—expected remaining life of 50 year old men has increased by 5 years since 1970.

Tables 1 and 2 provide further insight into the reasons for these trends. Table 1 uses age specific mortality data to decompose inter-decade changes in longevity into contributions from various age intervals. The estimates show the additional life years contributed by declining mortality rates in each age interval and decade; for example, between 1910 and 1920 lower male infant mortality (<1 year old) contributed 2.48 of the 4.85 expected life-years gained over the decade. The table demonstrates important age and gender differences in the timing of life-extending improvements in health. Over the century reductions in infant (<1) and child (1-14) mortality were the major contributing factors to increasing lifespans, yet almost all (85%) of these gains occurred before 1950. This partially explains the slowdown in overall growth that occurred from 1950 to 1970. In contrast, the renewal of growth that occurred after 1970 is largely accounted for by declining mortality among older Americans. For example, the contribution of reduced mortality among men aged 55 and over was negligible before 1970, but since then declining death rates of older men have added 3.9 years to expected lifetimes. This is more than half of the total male gain over that period. Women's gains at older ages began earlier, in the 1940's, but slowed relative to men's gains after 1980.[3]

This shift in the age distribution of rising longevity reflects differential progress against life-threatening ailments, shown in Table 2. The importance of declining mortality from afflictions that strike older individuals is clear. Since 1950 the largest single contributor is reduced mortality from heart disease, which added more than 3.5 years to the expected lifetimes of both men and women, accounting for more than 40 percent of the total. When combined with strokes, progress against cardiovascular diseases added 4.7 and 5.1 years to the expected lifetimes of men and women, with most of the gain occurring after 1970.[4]

These data are the foundation for the problem we study. Rising longevity, and health improvements more generally, are a form of economic progress. Valuation of these gains is important for two reasons. First, traditional measures of economic growth and welfare, based on national income accounts, make no attempt to account for this source of rising living standards. They therefore underestimate improvements in well-being. Second, public expenditure accounts for a large portion of both medical research and the provision of

[3] Evidence for other developed countries roughly conforms to the data in Figure 1 and Tables 1 and 2. For OECD countries as a whole, from 1960 to 2000 the average at-birth life expectancy of women increased by 9 years and that of men by 8 years. OECD Health Data, Table 1, Life Expectancy in Years, http://www.oecd.org/xls/M00031000/M00031357.xls .

[4] These tabulations indicate little progress against cancer. This is partly an artifact of the way the underlying data are aggregated. Closer examination (we do not provide the details here) shows declining cancer mortality at younger ages and rising mortality at older ones, with the overall age-adjusted rate fairly constant. This may reflect selection: those who would have died from heart disease at younger ages may also be more prone to die from cancer later in life.

medical care. Efficient decisions require a framework for measuring the value of treatment, and of research-based medical progress.

III. Economic Framework: Valuing Improvements in Health

Advances in medical knowledge can take many forms, ranging from the development of new medicines and techniques for treating disease to improvements in public health infrastructure. These advances affect the quality of life and the risks of mortality at various stages of the lifecycle. We assume that these effects are channeled through the intangible "health" of individuals, of which we distinguish two types. The first, $H(t)$, raises the quality of life without affecting mortality. For example, new medicines that improve mental health, cure migraine headaches, or reduce the effects of arthritis will increase instantaneous utility without necessarily affecting the length of life. The other, $G(t)$, affects mortality without affecting the quality of life. New methods of detecting treatable diseases or advances in surgical techniques are examples. Of course, many advances in medical knowledge affect both types of health. New medicines that reduce blood pressure or retard the advance of cancer can raise both the quality of life and its duration. $H(t)$ and $G(t)$ are affected by the state of medical knowledge and also by individuals' choices, but we relegate these choices to the background.

How much are people willing to pay for improvements in health? We build on the lifecycle analyses of Arthur (1981) and Rosen (1988, 1994) by assuming that willingness to pay is determined by the expected discounted present value of lifetime utility.[5] Write remaining lifetime expected utility for a representative individual of age a as

[5] Arthur (1981) and Rosen (1988, 1994) analyze the value of changes in longevity derived from lifetime expected utility. They ignore quality of life (our H), the value of non-market time, and variation in the value

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

where ρ is the rate of time preference. We adopt the normalization that the utility of death is zero. Notice in (1) that *H(t)* enters multiplicatively, so improvements in type-*H* health enhance the "quality" of life by increasing instantaneous utility from consumption, *c(t)*, and non-market time, *l(t)*.[6] Type-*G* health enters (1) through the survivor function:

(2) $$\tilde{S}(t,a) = \exp[-\int_a^t \lambda(\tau, G(\tau))d\tau]$$

In (2), $\lambda(\tau, G(\tau))$ is the instantaneous mortality rate (hazard function) and $\tilde{S}(t,a)$ is the probability that the agent survives from age *a* to age *t*. We assume that $\lambda_G \equiv \partial\lambda / \partial G < 0$ so that an increase in type-*G* health reduces mortality and increases the survivor function.

Notice from (2) that any factor that affects the instantaneous hazard of death, λ, affects the survivor function in proportion to the survivor function itself. Formally, for any factor α that shifts the hazard at particular ages the impact on $\tilde{S}(t,a)$ is

(3) $$\frac{\partial \tilde{S}(t,a)}{\partial \alpha} \equiv \tilde{S}'_\alpha(t,a) = -\tilde{S}(t,a)\int_a^t \lambda'_\alpha(\tau, G(\tau))d\tau = \tilde{S}(t,a)\Gamma_\alpha(t,a)$$

A given change in the hazard at some age prior to *t* has a larger impact on the probability $\tilde{S}(t,a)$ when $\tilde{S}(t,a)$ is itself large. We return to the implications of this point later.

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of a life-year over the lifecycle. Our equation (11), below, incorporates estimates of the value of non-market time and the value of improvements to health while living in assessing the value of health improvements.

[6] This specification for *H* is consistent with empirical methods for evaluating the quality of life for individuals with various ailments. The most popular method asks individuals to index their current quality of a life-year against what they would achieve if they were in "perfect" health. The resulting "Quality Adjusted Life Years" (QALY) gives values of $H \le 1$, where $H=1$ indexes perfect health.

To close the lifecycle problem, we must specify a budget constraint. We assume a perfect annuity market, which means that at each age *a* the lifetime expected discounted value of future consumption must equal expected lifetime wealth

$$A(a)+\int_a^{\infty}[y(t)-c(t)]\tilde{S}(t,a)e^{-r(t-a)}dt \quad = \quad 0 \tag{4}$$

where *r* is the interest rate, *A(a)* is initial assets at age *a*, and *y(t)* is income at age *t*.[7] Equation (4) is the lifecycle equivalent of a complete market for consumption insurance. With endogenous labor supply, *y(t)* is determined by the choice of *l(t),* $y(t)=w(t)[1-l(t)]+b(t)$, where we normalize the maximum amount of non-market time at unity and *b(t)* is life-contingent income such as social security or defined-benefit pension receipts.

The individual chooses *c(t)* and *l(t)* to maximize (1) subject to (4)

$$U(a)=\int_a^{\infty}\{H(t)u(c(t),l(t))e^{-\rho(t-a)}+\mu[y(t)-c(t)]e^{-r(t-a)}\}\tilde{S}(t,a)dt+\mu A(a) \tag{5}$$

where μ is the multiplier associated with constraint (4).[8] Optimization yields the familiar necessary conditions

$$\begin{aligned} H(t)u_c'(c(t),l(t)) &= \mu e^{-(r-\rho)(t-a)} \\ H(t)u_l'(c(t),l(t)) &= w(t)\mu e^{-(r-\rho)(t-a)} \end{aligned} \tag{6}$$

Notice that *H(t)* and consumption of other goods are natural complements in our setup. For example, if type-*H* health declines at older ages (6) implies that consumption will decline as

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[7] Later we briefly consider the polar opposite case of zero saving and borrowing, so that *c(t)=y(t)* for all *t.*
[8] We have simplified by ignoring personal medical expenditures, which might be treated as a non-consumption expense. We return to a consideration of medical expenditures and the costs of health care in our empirical work.

well.[9] This is consistent with empirical studies of lifecycle consumption, and we exploit this feature below in calibrating the value of a life-year.

Equation (5) is our basic building block for thinking about factors such as medical knowledge that provide value by improving health. Before turning to those issues, notice that (5) and (6) provide a dollar figure for the "value of a life." Consider a small change $d\lambda(a)$ in the instantaneous hazard of death at age *a*. Using the properties of the survivor function in (2), $d\lambda(a) < 0$ increases survivorship in all future periods of life. The effect on expected lifetime utility is

$$dU(a) = -d\lambda(a)\int_a^\infty \{H(t)u(c(t),l(t))e^{-\rho(t-a)} + \mu[y(t)-c(t)]e^{-r(t-a)}\}\tilde{S}(t)dt$$

The value of remaining life at age *a* is the marginal rate of substitution between changes in $\lambda(a)$ and assets, *A(a)*:

$$V_\lambda(a) \equiv -\frac{\partial U(a)/\partial\lambda(a)}{\partial U(a)/\partial A(a)} = \frac{1}{\mu}\int_a^\infty \{H(t)u(c(t),l(t))e^{-\rho(t-a)} + \mu[y(t)-c(t)]e^{-r(t-a)}\}\tilde{S}(t)dt$$

Using (6),

(7) $$V_\lambda(a) = \int_a^\infty v(t)e^{-r(t-a)}\tilde{S}(t,a)dt$$

where

(8) $$v(t) = \frac{u(c(t),l(t))}{u_c'} - c(t) + y(t)$$

[9] A sufficient condition for health and consumption to move together over the lifecycle is $u_{cl}(c,l) \geq 0$ -- leisure does not reduce the marginal utility of consumption. If u_{cl}'' sufficiently negative, then consumption can rise as health falls.

is the "value of a life-year": the monetary value of instantaneous utility $\frac{u(c,l)}{u_c'}$ *plus* net savings that accrue at age *t*. Net savings at age *t* increase the value of a life-year because they are used to finance consumption in other periods, with marginal utility μ. Notice that the personal rate of time preference, ρ, does not appear in (7): the ability to borrow and lend means that the expected value of a future life-year is discounted at the market rate of interest, *r*. As both interest and mortality cause future life-years to be discounted, we define $S(t,a) \equiv e^{-r(t-a)}\tilde{S}(t,a)$ as the "discounted survivor function."

Similarly *H(t)* does not appear explicitly in the value of life formula (7). For example, think of two individuals, *A* and *B*, with identical mortality and wealth, but where person *A* has uniformly greater *H(t)*. Then (7) indicates that the monetary value of a life will be the same for *A* and *B* because type-*H* health raises total utility and the marginal utility of consumption by the same proportional amount. Put differently, the marginal rate of substitution between "life" (or the probability of living) and consumption does not depend on health.[10] This does not mean that health has no value, however; it simply says that willingness to pay for changes in survival do not depend on the level of health. This property is consistent with empirical evidence, as summarized by the Environmental Protection Agency's Science Advisory Board (2000):

> "There are no published studies that show that persons with physical limitations or chronic illnesses are willing to pay less to increase their longevity than persons without those limitations. People with physical limitations appear to adjust to their

[10] Think of a utility function for three goods: (1) health, *H*, (2) the probability of surviving a given period of time, *S*; and (3) consumption, *c*. If utility is of the form *v(H)u(S,c)* then the marginal rate of substitution between S and c does not depend on *H*. Nevertheless, *H* is valuable, with marginal value $v'(H)/u_c(S,c)$.

conditions, and their willingness to pay to reduce fatal risks is therefore not affected."[11]

Life-Cycle Changes in the Value of Life

While differences in type-*H* health between individuals do not generate corresponding differences in the value of life, life-cycle changes in type-*H* health and income affect the age profile of the value of a life-year. Adopting the notation $\dot{x} = d \log x(t) / dt$, differentiation of (8) yields the rate of change in the value of a life-year as an individual ages:

$$\text{(9)} \qquad \dot{v}(t) = \frac{y(t)}{v(t)} \quad s_w(t)\,\dot{w}(t) + (1 - s_w(t))\,\dot{b}(t) \quad + \quad 1 - \frac{y(t) - c(t)}{v(t)} \quad \dot{H}(t) + r - \rho$$

where s_w is the share of labor earnings in total life-contingent income. The first term in (9) ties the age profile of *v(t)* to changes in income. Pre-retirement we can set s_w=1, so the value of a life-year tracks the age profile of wages. Indexing of post-retirement annuity incomes suggests $\dot{b}$ =0 is a good approximation for retired persons. The second term ties life-cycle changes in *v(t)* to changes in health and to time preference. Complementarity between type-*H* health and consumption of goods and leisure in (6) causes the value of a life-year to fall as health declines ($\dot{H} < 0$) in old age, so persons with declining health are, in effect, more impatient. In our later empirical work we assign a value to $\dot{H}$ based on lifecycle patterns of consumption, which causes life-years to become less valuable at older ages.

[11] http://www.epa.gov/sab/pdf/eeacf013.pdf

Cost-benefit evaluations that apply employ empirical estimates of the value of a statistical life (VSL), and the empirical studies on which they are founded, typically assume that VSLs do not depend on age. Then it is just as valuable to "save" a 60 year old as a 40 year old. Our framework indicates that the value of remaining life is age dependent, first rising and then falling as a person ages. From (7) the value of remaining life satisfies the usual law of motion for an asset price:

$$\frac{\partial V_\lambda(a)}{\partial a} = (r + \lambda(a))V_\lambda(a) - v(a)$$

Letting *R(a)* represent the (discounted) length of remaining life at age *a*, this becomes

$$\text{(10)} \qquad \frac{\partial V_\lambda(a)}{\partial a} = (r + \lambda(a))\int_a^\infty [v(t) - v(a)]S(t,a)dt + v(a)\frac{\partial R(a)}{\partial a}$$

Life tables for the United States and other developed economies indicate that the last term is negative at all ages—surviving another year reduces the length of remaining life—though it is conceivably positive in situations where the young are at particularly high risk of death, say due to childhood disease or violence. The first term is positive (negative) if the future is "better" (worse), on average, than the present. From (9), this term will be positive at younger ages because wages typically rise with age and because health is unlikely to deteriorate much among the young. Later in life, when wage growth is negligible, $V_\lambda(a)$ must decline as persons age because type-*H* health deteriorates ($v(t) < v(a)$ for $t > a$) and because the remaining length of life is falling.

Willingness to Pay for Improvements in Health

To see how this framework can be used to evaluate improvements in health, consider some factor, α, that can affect both the type-*H* and type-*G* concepts of health. For purposes of subsequent discussion we will refer to α as the state of "medical knowledge"—techniques, medicines, and so on—though it can equally represent factors that improve public health, such as environmental improvements, improved nutrition or access to medical care. The marginal value of some improvement in medical knowledge follows from the displacement of (5):

(11) $$V_\alpha(a) \equiv \frac{U'_\alpha(a)}{\mu} = \int_a^\infty v(t)S(t,a)\Gamma_\alpha(t,a)dt + \int_a^\infty \frac{H'_\alpha(t)}{H(t)}\frac{u(c(t),l(t))}{u_c}S(t,a)dt$$

Equation (11) measures the change in value of life induced by changes in any factor that affects type-*H* or type-*G* health. The first term in (11) is the dollar value of the gain in lifetime expected utility from changes in mortality, indexed by changes in the survivor function $S(t,a)\Gamma_\alpha(t,a) = \dfrac{\partial S(t,a)}{\partial \alpha}$. These changes in the probability of survival weight the value of a life-year in each period where mortality changes.

The second term is the value of changes in type-*H* health at each age, $H'_\alpha(t) \equiv \partial H(t)/\partial\alpha$, that raise quality of life while holding mortality fixed. These improvements weight utility itself, with no contribution from net savings. Notice that when savings are negligible, proportional changes in type-*H* health (H'_α / H) and in the survivor function (Γ_α) are valued in exactly the same way. Living a bit better is like living a bit longer.

Equation (11) is the foundation for our efforts to value past and prospective changes in longevity and the quality of life. To make empirical headway we restrict utility to be homothetic, so $u(c,l) \equiv u(z(c,l))$ where *z* is homogeneous of degree one. Then the dollar value of a life-year is (suppressing time arguments)

$$v = y + \frac{u(c,l)}{u_c(c,l)} - c = y + \frac{u(z_c c + z_l l)}{z_c u'(z)} - c \qquad (12)$$

so *z* is a composite commodity that aggregates consumption and non-market time. Define *full consumption* and *full income* by adding the shadow value of non-market time to consumption and income:

$$c^F = c + \frac{z_l}{z_c} l = z_c^{-1} z$$

$$y^F = y + \frac{z_l}{z_c} l$$

where for labor force participants we know that $\frac{u_l(z)}{u_c(z)} = \frac{z_l}{z_c} = w$, the market wage. Then

$$v = y + \frac{u(z_c c + z_l l)}{z_c u'(z)} - c = y^F + c^F \quad \frac{u(z)}{zu'(z)} - 1$$

or

$$v = y^F + c^F \Phi(z) \qquad (13)$$

In (13), $\Phi(z)$ is consumer surplus per unit of the composite commodity *z*, which is identical to surplus per dollar of full consumption. It is positive when average utility of *z* is greater than marginal utility, or equivalently when the elasticity of utility with respect to *z* is smaller than 1.0. The theory does not imply that $\Phi(z) \geq 0$, however. Positive utility may require composite consumption above some minimum subsistence level, z_0, where $u(z_0) = 0$. Then $\Phi(z_0) = -1$ and, by monotonicity of surplus, there is a $z_1 > z_0$ where $\Phi(z_1) = 0$.[12]

Equation (13) demonstrates two important points about the value of a life-year. First, even if $\Phi(z) = 0$ the value of being alive exceeds measured income because of the value of non-market time. This is especially important for persons without wage and salary income—such as the retired—for whom the value of non-market time accounts for most of y^F. For full-time workers non-working hours are valued at *w* and annual hours of leisure are (reasonably) greater than hours worked, so that y^F may be more than double money income. Second, full consumption adds to this value so long as $\Phi(z) > 0$. For example, if $\Phi(z) = 1$ (surplus equals consumption expenditure) and *y=c* (no savings), then the value of a life year would be more than 4 times annual income. For a typical male at peak lifecycle earnings—roughly \$45,000 per year around age 50—this would put the value of a life year above \$180,000. The evidence we develop below suggests it is larger still.

Now use (13) to rewrite (7) and (11):

(14) $$V_\lambda(a) = \int_a^\infty [y^F(t) + c^F(t)\Phi(z(t))]S(t,a)dt$$

(15) $$V_\alpha(a) = \int_a^\infty [y^F(t) + c^F(t)\Phi(z(t))]S(t,a)\Gamma_\alpha(t,a)dt \;+\; \int_a^\infty \frac{H'_\alpha(t)}{H(t)} c^F(t)[1+\Phi(z(t))]S(t,a)dt$$

[12] Note that *v(t)<0* doesn't mean that death is preferred, as the value of continued life at *a* is determined by $V_\lambda(a)$ which will be positive if future prospects are brighter.

Equation (14) is the value of an age-*a* statistical life, which is the expected discounted value of full income and surplus on full consumption. Equation (15) is the age-*a* willingness to pay for improvements in health. Both are proportional to full income and consumption, implying that health is perhaps the ultimate "normal" good. To pursue this point let $\sigma(z) = -\frac{u'(z)}{zu''(z)}$ denote the elasticity of intertemporal substitution (*EIS*) in consumption, and consider the impact of increased income or wealth on *v(t).* Abstracting from saving by setting *y*=*c*, the income elasticity of *v(t)* is

(16) $$\frac{\partial \log v}{\partial \log y} = 1 + \frac{1}{\sigma(z)} - \frac{1}{1+\Phi(z)^{-1}}$$

which is larger than 1.0 if $\sigma(z) < 1 + \frac{1}{\Phi(z)}$. Evidence developed below indicates $\Phi(z) \approx 2$ for prime-aged individuals, and empirical estimates of the *EIS* suggests $\sigma(z) = 1.0$ as a rough upper bound, so the condition is likely satisfied—with these values the income elasticity of the value of a life year is 1.33. It would be larger still for values of $\sigma(z) < 1.0$, as are common found in empirical applications.[13]

Equations (14)-(16) have a number of implications for valuing improvements in health and health-related investments.

1. Willingness to pay for improvements in health is proportional to full income and full consumption, so willingness to pay rises with wealth. That wealthier individuals are willing to pay more for improvements in health may seem obvious, but the broader implication is that economic growth is a boon to health-related investments. This is especially important when willingness to pay for health improvements is income elastic,

as suggested by (16). Then richer societies invest proportionally more in health because life itself is more valuable.[14]

2. The relevant concepts of income and consumption include the shadow value of non-market time. Common attempts to value life-years based on income or consumption expenditures alone will miss a large part of what people value, especially when health improvements are concentrated at older ages.[15]

3. Wealth constant, improvements in both type-*G* and type-*H* health are more valuable when surplus per dollar of full consumption, Φ, is large. Intuitively, Φ is large when the demand for *current* consumption is inelastic, so that consumption expenditures at different ages are poor substitutes—$\sigma(z)$ is small. Then loss of a year of life cannot be offset by simply reallocating consumption to other years. We exploit this notion in the next section, gauging Φ from evidence on intertemporal substitution in consumption.

4. For given profiles of income and consumption, the value of a reduction in mortality (Γ_α) or an improvement in the quality of life (H'_α / H) is larger when $S(t,a)$ is large. This suggests a form of increasing returns in health improvements: medical and other advances that reduce mortality raise the value of *further* advances, because individuals are more likely to be alive to enjoy the benefits. So health-related investments are likely to be more valuable to already healthy individuals, and in societies where average health is already high. We develop this point more completely in Section V.

5. The value of progress against a particular disease is greatest when the current age, *a*, is close to, but before, the typical age of onset of the disease. For example, for an ailment like cardiovascular disease, mortality-reducing progress (Γ_α) is likely to be concentrated at ages 50 and above. Then the expected present value of such progress will be greater at age 45 than at ages 25 or 90 because of both discounting and survivorship. Thus we

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[13] Section IV discusses empirical evidence on $\sigma(z)$.

[14] Our estimates of the value of a life year are based on empirical estimates of the value of a statistical life (VSL), as surveyed in Viscusi (1992) and Viscusi and Aldy (2003). Based on comparisons of VSLs across countries Viscusi and Aldy conclude that the income elasticity of the value of a statistical life is about 0.6.

[15] For example, the Conference Board of Canada's (2001) estimates the "costs" of excess mortality based on what a decedent would have produced, not the value to the individual of remaining alive.

estimate in Section VI that a 10% reduction in mortality from heart disease would be worth about $30,000 to a 45-year old male but only about $15,000 to men aged 25 or 90. Similarly, progress against Alzheimer's that improves the quality of life ($H'_\alpha / H > 0$) will be more valuable to 60 year-olds than to 30 year-olds.

IV. Calibration: The Value of a Life-year

Our calibration strategy begins with estimates of "the value of a statistical life" taken from the literature on willingness to pay for reductions in risks of accidental death (see Viscusi (1992) for a survey or Thaler and Rosen (1975) for an original analysis). These studies estimate willingness to pay from wage differences on jobs with varying probabilities of accidental death, or from market prices for products (such as airbags) that reduce the likelihood of a fatal injury. For example, suppose that workers in a particular occupation require a $500 annual wage premium in order to accept a 1 in 10,000 increase in the annual probability of accidental death. In a population of 10,000 workers this change in risk would raise expected deaths by 1 each year, with an aggregate value of $\$500 \times 10{,}000 = \$5$ million. Then the value of one statistical life is $5 million. In our framework this is the conceptual equivalent of the value of remaining life given by $V_\lambda(a)$ in (14).

According to Viscusi's (1993) survey, this literature yields a "reasonable range" of values for $V_\lambda(a)$ of $4 million to $9 million per statistical life, expressed in current (2004) dollars, while Viscusi and Aldy (2003) provide a tighter range for U.S. data at $5.5 to $7.5 million. Government agencies and panels regularly update these estimates to account for economic growth, new methods, and evidence; for example since 1999 the Environmental Protection Agency used a value of $6.3 million per statistical life in its cost-benefit analyses.[16] For the calculations that follow we will assume that the survivorship-weighted average value of a statistical life for individuals between the ages of 25 and 55 is $6.3 million.

Given this *average* value in (14), it remains to impute a lifecycle shape for the value of a life-year, $v(t) = y^F(t) + c^F(t)\Phi(z(t))$, which in turn determines the lifecycle pattern of the value of a life (14) and willingness to pay for health improvements (15). We construct *v(t)* from the model's structure and empirical evidence on key parameters. Values of full income $y^F(t)$ for a representative individual can be constructed from lifecycle wage profiles, while the time paths of $c(t)$ and $c^F(t)$ satisfy

(17a) $$\dot{c} = \sigma(r-\rho) + \sigma\dot{H} - (\eta-\sigma)s_L\dot{w}$$

(17b) $$\dot{c}^F = \sigma(r-\rho) + \sigma\dot{H} - (1-\sigma)s_L\dot{w}$$

where s_L is the share of non-market time in full consumption and η is the elasticity of substitution between consumption and leisure in *z(c,l)*. We assume that σ and η are constants, which implies that *z(c.l)* is CES and that

(18) $$u(z) = \frac{z^{1-\sigma^{-1}} - z_0^{1-\sigma^{-1}}}{1-\sigma^{-1}} \quad \Rightarrow \quad \Phi(z) = \frac{1}{\sigma-1}\; 1-\sigma(\frac{z_0}{z})^{1-\sigma^{-1}}$$

where $u(z_0)$ =0. The value of a life-year will be larger when demand for current full consumption is more inelastic, which occurs when there is little intertemporal substitution in consumption.

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[16] http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0483-01.pdf/$File/EE-0483-01.pdf .

There is a substantial empirical literature seeking to estimate σ based on versions of (17a). Hansen and Singleton (1983), Hall (1988), and Campbell and Mankiw (1989) find that aggregate consumption growth is insensitive to changes in the real interest rate, so that σ is close to zero. This would imply unreasonably large values of a life-year because $\Phi(z)$ would be huge. Similarly Barsky et. al. (1997), using questionnaire responses, find an upper bound on σ of about 0.36. In contrast, Browning, Hansen, and Heckman (1999) survey estimates of σ from micro-data and conclude that the evidence favors a value for σ that is "a bit" larger than 1.0. We know of no formal evidence on an analogue of z_0 / z, though comparisons of living standards over time and across countries suggest that it is quite small. In effect, the ratio asks how much composite consumption individuals would sacrifice before they would rather be dead. Notice that this ratio must be sufficiently positive for values of $\sigma < 1$ to generate positive surplus in (18).

Table 3 shows values of a life-year for a 50 year-old male who earns annual wages and benefits of $60,000 for 2000 hours of work.[17] We assume that *y=c* for these calculations, which is reasonable at this point in the lifecycle,[18] and that full income and consumption are based on 4000 hours available for work and leisure. We calculate *v(t)* under various assumptions for the sizes of σ and z_0 / z. The values in the table are large. For example, for σ=1.0 the value of an age-50 life-year ranges from $193,000 ($\Phi(z) = 0.61$) when z_0 / z =.2 up to $360,000 ($\Phi(z) = 2.0$) when z_0 / z =.05. For purposes of

[17] Median annual earnings of men aged 45-54 who worked full time in 1999 were about $45,000, http://www.census.gov/hhes/income/earnings/call1usmale.html . Non-wage benefits average about 29% of total compensation for a typical worker, http://www.bls.gov/news.release/ecec.t01.htm .

[18] Consumer Expenditure Survey data indicate that households with a "reference person" aged 45-54 2002-2003 reported average after tax incomes of $53,195 and consumption expenditures of $46,353. http://www.bls.gov/cex/home.htm , Table 29.

the following calculations we assume $\sigma = .80$ at all ages and $z_0 / z = .10$ at age 50, yielding a value of a life-year of \$373,000 ($\Phi(z) = 2.11$) when $y=c$.

To complete the lifecycle calibration of *v(t)* we choose the parameters of (17) in order to fit lifecycle patterns of consumption, and *y(t)* to match lifecycle wages. We impute the shape of *y(t)* by estimating a standard human capital earnings function with a 4th order polynomial in years of labor market experience. Empirical studies of lifecycle consumption indicate that consumption expenditures peak around age 50 and then decline by about 2% per year thereafter.[19] This pattern is consistent with declining type-*H* health after middle-age, together with $r > \rho$, which we assume. Figure 2a shows our imputed lifecycle patterns of *v(t),* $y^F(t)$ and $c^F(t)$ that yield an average value of V_λ =\$6.3 million between ages 25 and 55.[20] The value of a life-year peaks at over \$350,000 around age 50, but falls by more than half by age 80 because consumption (health) declines. Figure 2b shows the implied shape of *H(t)* that is consistent with lifecycle consumption—type-*H* health is stable until age 40, but declines rapidly in late middle-age.

The values of a life-year shown in Figure 2a are large in comparison to values that have been used in some related studies, but these magnitudes are necessary in order to match empirical estimates of the value of a statistical life. Lichtenberg (2001) and Cutler et. al. (1998) apply a uniform value of \$25,000 per life year saved in valuing gains from new

[19] See Banks et. al. (1998) and Browning and Crossley (2001). Fernandez-Villaverde and Krueger (2004) track the lifecycle profile of consumption from age 20, using Consumer Expenditure Survey data. Their relative consumption index peaks at about 1.3 at age 50 and declines by about 2 percent per year thereafter. Using British data Banks et. al. (1998) find that consumption peaks at age 50, declines by 2 percent per year pre-retirement, and by about 1 percent per year post-retirement. In our calibrations, relative consumption peaks at 1.29 at age 50, with a rate of decline of 2 percent at age 60 and 1.5-2 percent thereafter.

[20] In addition to the assumptions stated in the text, we assume $r - \rho = .02, \eta = .50$ and equal present values of expected lifetime income and consumption from age 20 forward. We also assume that post-retirement life-contingent income replaces 50 percent of pre-retirement earnings, commencing at age 65. Further details are presented in Murphy and Topel (2005).

drugs and advances against heart disease. This value is less than *income* for a typical full-time worker, and almost certainly less than full income, so it appears inconsistent with both theory and the evidence mentioned above that puts the value of a statistical life in the $4-9 million range.[21] Other studies impute higher values. Moore and Viscusi (1988) estimate the value of a life-year at $175,000, while Miller, Calhoun, and Arthur (1990) estimate a value of $120,000, based on a $2 million value of a statistical life. None of these studies account for lifecycle changes in the value of a life-year, as implied by theory.

Figure 3 plots values of remaining life by age for men and women using values of *v(t)* from Figure 2a for both sexes. In these and following calculations we value life-years from birth to age 20 at their age 20 values. The curves differ because we apply gender-specific survivor functions, so imputed values of remaining life are higher for women because they live longer. The role of discounting, due to both interest and future mortality in *S(t,a)*, is apparent in the figure: the value of remaining life peaks at $7 million for persons in their early 30's, but declines smoothly thereafter even though the value of a life-year continues to rise until age 50. We estimate that the value of remaining life declines to $5 million at age 50 and to $2 million by age 70.

V. Further Results

Complementarity in Willingness to Pay for Health Improvements

As noted above, willingness to pay for health improvements in is larger the greater is the likelihood that one will be around to enjoy them; that is, the larger are future values of

[21] The purpose of the calculation in Cutler et. al. (1998) was to show that the value of additional life years offset the medical cost of achieving them. So a conservative value imputed to life-years gained simply

S(t,a). This suggests a form of complementarity in the willingness to pay for health advances. An improvement in type-*G* health that reduces mortality from cardiovascular disease, for example, raises future values of *S(t,a)*. This increases the value of advances against other mortality-causing diseases such as cancer. So there is a sort of increasing return inherent to medical progress: past success raises the value of new improvements in health. This complementarity is also important at the level of individual investments in health. A medical advance that raises future survival probabilities raises the return to individual investments in health such as diet and exercise that have their main benefit in the future.

To formalize these ideas, assume that there are only two diseases, call them *A* and *B,* that affect type-*H* or type-*G* health. To keep things simple, assume that *A (B)* affects one of type-*H* or type-*G* health, but not both. This means that an advance against *A* might reduce mortality but leave the "quality" of life, through *H*, unchanged. Other possibilities are simple combinations of the formulas that follow.

Consider first the case where *A* and *B* each affect mortality only. By the nature of competing risks we know $\lambda(t)=\lambda^{A}(t)+\lambda^{B}(t)$, where $\lambda^{j}(t)$ is the mortality hazard from disease *j*. Denote by $d\alpha$ $(d\beta)$ a medical advance that reduces mortality from *A* (*B*), so that $\frac{\partial\lambda^{A}(t)}{\partial\alpha}<0$.[22] Differentiation of (15) and some algebra yields

(19)
$$V_{\alpha\beta}(a)\equiv\frac{\partial V_{\alpha}(a)}{\partial\beta}=\int_{a}^{\infty}[y^{F}(t)+\Phi(z)c^{F}(t)]S(t,a)\Gamma_{\alpha}(t,a)\Gamma_{\beta}(t,a)dt$$
$$-\frac{\partial\ln\mu}{\partial\beta}\int_{a}^{\infty}[1+\Phi(z)]c^{F}(t)S(t,a)\Gamma_{\alpha}(t,a)dt$$

reinforced their point that benefits offset costs.

In (19) the functions $\Gamma_\alpha \geq 0$ and $\Gamma_\beta \geq 0$ are derivatives of $\ln S(t,a)$, defined in (3), and are non-decreasing in *t* and strictly positive for some values of *t*. This means that the first integral in (19) is strictly positive, reflecting the intuition stated above: Progress against heart disease (*A*) raises future values of *S(t,a)*. This makes progress against cancer (*B*) more valuable because the individual is more likely to be alive to enjoy the gains. Progress against cancer isn't worth much if you are sure to die of a heart attack first.

The second line of (19) is a wealth effect that occurs because people now expect to live longer, so lifecycle income must be spread over a longer life.[23] From the lifecycle budget constraint these adjustments must satisfy:

$$\int_a^\infty \frac{\partial c(t)}{\partial \beta} S(t,a)dt = \int_a^\infty [y(t) - c(t)]S(t,a)\Gamma_\beta(t,a)dt$$

Then using the definition of $\sigma(z)$:

$$\frac{\partial \ln \mu}{\partial \beta} = -\frac{\int_a^\infty [y(t) - c(t)]S(t,a)\Gamma_\beta(t,a)dt}{\int_a^\infty \sigma(z)c(t)S(t,a)dt} \tag{20}$$

If reductions in mortality from ailment *B* are weighted toward periods where net saving is positive, then consumption rises (marginal utility falls) and complementarity in (19) is assured. But if progress against *B* occurs mainly in periods of negative net saving the marginal utility of consumption must rise. For recent medical advances such as reductions in mortality from cardiovascular disease – which mainly strikes older, non-working individuals – lower per-period consumption is likely because savings must finance a longer

[22] To focus on essential ideas, we rule out the obvious case where progress against one disease, say *A,* affects mortality from *B*.
[23] Absent saving, so *y=c* in all periods, this term does not appear and complementarity is assured.

retirement when mortality falls.[24] Even so, for reasonable values of the parameters and empirically relevant savings rates this term is negligible. Then (19) is positive and we conclude that *mortality-reducing improvements in health are complementary.*

The next case we consider is when ailment *A* affects mortality (e.g. cancer) but *B* affects the quality of life through type-*H* health (e.g. Alzheimer's). Does progress against cancer raise the value of progress against Alzheimer's? As utility takes the form *Hu(z)*, we have ruled out the obvious case where willingness to pay depends directly on *H.*[25] Instead the effect is channeled though the complementarity of *H* with *z*: a medical advance that raises *H* at older ages, for example, causes a reallocation of lifecycle consumption, raising consumer surplus at older ages as well. This is complementary with reductions in mortality, which raise the probability of being alive at older ages. Formally, the displacement of the budget constraint when $d\beta > 0$ yields

$$(21) \qquad 0 = \int_a^\infty c^F(t) S(t,a) \sigma(z) [\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta}] dt$$

because in this case the survivor function is unaffected by $d\beta$. If the improvement in health is age-neutral ($\frac{\partial \ln H}{\partial \beta}$ is constant) then $\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta} = 0$ at all ages because the consumption profile is unchanged. But if proportional changes in *H* are larger at older ages, such as for progress against diseases like Alzheimer's or arthritis, then $\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta}$ is

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[24] We ignore other indirect effects that would reinforce complementarity by increasing *y(t)*, such as delayed retirement or increased investment in human capital.

[25] That is, we have ruled out the case where an increase in *H* has a larger impact on utility than on the marginal utility of consumption. In that case, progress against Alzheimer's (for example) would raise the value of a life year among the elderly, reinforcing complementarity with other advances that reduce mortality.

negative at young ages and positive at older ones. This fact is useful in evaluating complementarity in willingness to pay, determined by

(22) $$V_{\alpha\beta}(a) = \int_a^\infty \frac{1+\Phi(z)}{\sigma(z)} \Gamma_\alpha(t,a) c^F(t) S(t,a) \sigma(z) [\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta}] dt$$

In (22) the integrand from (21) is multiplied by $\frac{1+\Phi(z)}{\sigma(z)} \Gamma_\alpha(t,a)$. If $\frac{1+\Phi}{\sigma}$ is constant, then since $\Gamma_\alpha(t,a)$ is non-decreasing the sign of (22) is determined by whether improvements in H rise or fall with age. In particular, (22) is positive if $\frac{\partial \ln H(t)}{\partial \beta}$ rises with age, because then $\Gamma_\alpha(t,a)$ gives greater weight to positive values of $\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta}$.   This means that *mortality-reducing medical advances are complementary with type-H health improvements that increase with age*. For example, advances against heart disease raise willingness to pay for progress against Alzheimer's and arthritis.

The last case to consider is when afflictions *A* and *B* both affect type-*H* health, but not mortality. Then complementarity is determined by the sign of

(23) $$V_{\alpha\beta}(a) = \int_a^\infty [1 + \frac{1+\Phi(z)}{\sigma(z)}] c^F(t) S(t,a) \sigma(z) \frac{\partial \ln H(t)}{\partial \alpha} [\frac{\partial \ln H(t)}{\partial \beta} - \frac{\partial \ln \mu}{\partial \beta}] dt$$

Again assuming $\frac{1+\Phi}{\sigma}$ constant, comparison with (21) indicates that $V_{\alpha\beta} > 0$ when $\frac{\partial \ln H(t)}{\partial \alpha}$ gives largest weight at ages when $\frac{\partial \ln H(t)}{\partial \beta}$ is large. So age-increasing advances (e.g. against arthritis and Alzheimer's) tend to be complements, as are age-decreasing ones (e.g. against non-fatal childhood ailments).

This analysis has yielded three additional implications:

6. Mortality-reducing (type-*G*) improvements in health tend to be complementary: reductions in mortality from one disease raise the value of progress against other life-threatening ailments. So progress against heart disease raises the value of progress against cancer.

7. Mortality reducing improvements in health raise the value of type-*H* improvements that increase with age. So reductions in mortality from heart disease raise the value of progress against Alzheimer's or arthritis.

8. Type-*H* improvements in health that increase with age are complementary with one another. Progress against Alzheimer's raises the value of progress against arthritis.

The Social Value of Improvements in Health

The framework set out above values health improvements by measuring willingness to pay for a representative individual. Our main interest is in assessing the value of medical advances or improvements in public health infrastructure that increase society's "output" of health. These advances typically affect both current and future populations, so to measure the social value of such advances we must aggregate over the current and expected future populations that benefit. If (15) represents an individual's willingness to pay for health improvements, then the current social value of advances that improve health from date τ onward is:

(24) $$W_\alpha(\tau) = \int_{a=0}^{\infty} N(a,\tau)V_\alpha(a)da \ + \ N^f(\tau)V_\alpha(0)$$

Here $N(a,\tau)$ is the population of age a at date τ and $N^f(\tau)$ is the present discounted value of the number of births in future years. These enter the calculation because a medical advance that improves the health of the current population will also apply to future generations, for whom value is measured at birth. When combined with (15), equation (24) yields two additional implications.

9. The current social value of a medical advance is proportional to the size of the current and future populations to which it applies.

10. Aggregate willingness to pay for progress against a particular disease will be highest when the age distribution of the population is concentrated near, but before, the typical age of onset of the disease. For example, the aging of the baby-boom generation has raised the social value of medical advances against age-related ailments.

In our empirical applications we will apply (24) to mortality data in three ways. First, treating reductions in mortality at any past date τ as the outcome of technical improvements that increase health output, we will augment date-τ national income to include the value of life-years "produced". Second, we use (24) to calculate what past reductions in mortality are worth today. For example, we calculate the current value of reductions in mortality from heart disease that occurred between 1970 and 2000. Third, we use (24) to calculate the prospective value of medical progress that would, say, reduce the average likelihood of dying from cancer by some amount.

VI. Estimating the Value of Past and Prospective Health Improvements

This section applies the model of Sections III-V to measure long-term gains in the value of life, the disease-specific sources of those gains, and the prospective values of future progress against life-threatening diseases. We also show how to account for changes in medical expenditures that accompany life-extending medical progress, which is a central feature of cost-benefit analyses of improving health care. We begin by gauging the size, timing, and age-distribution of gains over the 20th century.

Valuing Longevity Gains over the 20th Century

Using age and gender specific mortality tables for the United States that begin in 1900, Figures 4a-b show the timing and age distribution of increases in the value of life over the 20th century. For these calculations, we value additional life-years at past dates at current willingness to pay, using the age profile of values shown in Figure 2a. In other words, the figures show the value received by individuals of a particular age *today* from health-improving advances that were achieved in the past. Vertical differences between two curves represent the present discounted value of changes in survivor rates accruing to individuals of a particular age for a particular decade, so the top curve (2000) shows cumulative gains from 1900 to 2000, and so on.

For both men and women the largest gains in the value of life are at birth and at young ages, representing large declines in infant mortality and deaths from childhood diseases. We estimate that health improvements from all sources and at all ages over the 20th century yielded additional life years for a new born male or female with a present discounted value of nearly $2 million. Most of the gains for newborns occurred in the early decades of the century – more than half occurred by 1930 and more than 80 percent had been realized by 1950, reflecting substantial progress against infant and childhood mortality in the first half of the century. But gains are also very substantial for adults. Men aged 20 to 40 gained additional life-years worth roughly $1 million, valued at current implicit prices. Women's gains in these "prime" years were even larger, peaking at nearly $1.2 million for women in their early 30s. This reflects the fact that expected remaining durations of life increased by more for women than for men, as we value life years for men and women at the same implicit prices. Importantly for what follows, Figures 4a-b show negligible progress for women after 1980, though men enjoyed substantial gains over this period.

Even among adults, the gains by age were unevenly distributed over the century. Roughly three-fourths of the $1 million gain enjoyed by 20 year old men had occurred by 1960, but the corresponding proportion for 40 year olds is about half and among 60 year olds it is substantially less than half. In other words, progress during the first half of the 20th century disproportionately benefited the young, but progress at the end of the century shifted toward older individuals, reflecting (as we shall see) progress against heart disease, stroke, and other older-age ailments.

To evaluate whether these estimates are reasonable, consider the $1 million gain enjoyed by a 30 year old male. Over the century, the expected remaining duration of life for 30 year old men increased by 11.3 years, from 34.9 to 46.2. So think of a current 30 year old who is offered the choice of (a) his current standard of living and health or (b) a lump sum of $1 million and the life-expectancy of 30 year old in 1900, which is 11.3 years shorter. Our estimates imply that the choice is a close call, but for a payment of less than $1 million he would keep his current health. For women, the corresponding gain in life expectancy is 14.9 years, from 36.4 to 50.5, which is worth nearly $1.2 million. If the reader thinks that it would take greater payments than these to induce a trade, then our estimates are conservative.

Figure 5 further documents the difference in timing between men's and women's cumulative gains. We graph age-weighted average gains for men and women over the entire century, using end-of-century population weights. These gains cumulate to $1.3 million for the representative individual of each sex. Notice that women's gains started to outpace men's in the 1930s and that progress for both men and women decelerated in the early 1950s, reflecting the near-exhaustion of potential progress against infant and child mortality. For men, progress stalled for 20 years, so that the female-male gap in value gained reached nearly $180,000 by 1970. But male progress resumed after 1970, reflecting advances against adult ailments (see Figure 4), and the female-male disparity had vanished by the end of the century.

The estimates in Figures 4a-b value past gains at current willingness to pay, so they represent the current value of past progress—what people alive today gained from earlier improvements. Another way to illustrate the importance of health progress is to value mortality-reducing progress using willingness to pay at the date it occurs, so newly "produced" life years are a component of output—health capital—that is uncounted in national income accounts.[26] The result is a sort of "health augmented" measure of per-capita national output that counts the present value of reduced mortality at the date it is observed. Table 4 reports the results of this exercise.

From 1900 to 1950 the average per-capita value of new life-years "produced" through declining mortality was roughly equal to average output of goods and services. The

[26] To measure willingness to pay in each period we maintain the shape of $v(t)$ in 2000, but rescale its level according to the ratio of GDP per capita in year τ and in 2000.

decade from 1910-20 is an exception, reflecting the impact of the flu pandemic of 1917-19. Gains after 1950 form a smaller share of “output” per person because other forms of productivity have grown faster. Taking account of health capital in this way also changes one’s perspective on relative growth rates from different decades: per-capita GDP grew rapidly during the 1960s and slowly during the 1970s, yet production of this measure of health stagnated in the 1960s—it was lower than at any other time during the century—but boomed in the 1970s.

Post-1970 Gains

Figures 4 and 5 showed a resumption of mortality-reducing health progress after 1970, which was concentrated at older ages and greater for men than for women. We now turn to a more detailed examination of this episode.

Figures 6a-b show the timing and age-distribution of gains after 1970. In contrast to the century-long gains shown above, the largest gains after 1970 accrue to persons between ages 40 and 60, reflecting progress against ailments that affect older individuals. Cumulative gains for men peak at over $460,000 for 50 year olds (who gained about 5 years of life-expectancy), which is about double the peak cumulative gains of women (who gained 2.8 years) over this period. Most of these gains, and most of the difference between the gains of men and women, are due to substantial progress against heart disease alone (Figure 7), which kills more men, at earlier ages, than women. Reduced mortality from heart disease over this 30-year interval was worth nearly $300,000 to a prime-aged male (Figure 8), which was roughly three-fourths of the overall increase in the value of remaining life. This partially accounts for the late-century “convergence” of men’s and women’s gains, due to a sharp deceleration in women's progress after 1980 (Figure 6b). This fact will prove important below, when we deduct rising expenditures for medical care from these values.

Table 5 reports the social value of these gains, using (24) to aggregate private values over end-of-century and expected future populations. So, for example, the 1970-80 gain of $188,015 for 45-54 year old men represents what men of that age in 2000 would be willing to pay to have 1980 survival rates instead of 1970 survival rates. This gain applies to a population of 15.8 million men, and so on. The population at birth represents the present discounted value (at 3%) of projected birth cohorts, as estimated by the U.S. Bureau of the Census.[27]

The numbers are huge because the population to which per-person gains are applied is large. For men, mortality reductions that were achieved between 1970 and 1980 have an aggregate present discounted value of $27 *trillion.* Progress slowed somewhat after 1980, but even so the cumulative post-1970 gains for men total $61 trillion. Women's gains, which total "only" $34 trillion over the full period, decline sharply relative to men's after 1980. Combining men's and women's gains, reductions in mortality between 1970 and 2000 yielded additional life-years with an end-of-century value of $95 trillion, or about $3.1 trillion per year. Of this amount, separate calculations show that about two-thirds ($64 trillion) accrued to persons alive in 2000, and one-third will be enjoyed by future birth cohorts.

Net Gains: Deducting the Rising Costs of Medical Care

[27] http://www.census.gov/ipc/www/usinterimproj/ , Table 2A.

To be economically worthwhile the benefits of health improvements must offset the costs of achieving them. These costs have two basic components. The first is the up-front cost of developing new health-improving technologies, which take the form of medical research and development expenditures, broadly defined. The second is the cost of actually implementing new procedures and treatments, which takes the form of direct medical expenditures. These costs can either rise or fall as a consequence of technical advances, depending on the nature of the advance and the nature of demand for medical services.

We defer for the moment a discussion of development costs. Health expenditures can be accounted for by a straightforward extension of the earlier analysis. We assume that health expenditures at age *t*, *k(t)*, provide no direct utility beyond their necessity for maintaining health. Then a health-improving technical advance ($d\alpha > 0$) may improve both longevity and the quality of life while also changing the costs of health care. Willingness to pay for such an advance is a simple extension of (15):

$$V_\alpha(a) = \int_a^\infty [y^F(t) - k(t) + c^F(t)\Phi(z(t))](S_\alpha(t,a) + S_k(t,a)k_\alpha(t))dt - \int_a^\infty k_\alpha(t)S(t,a)dt$$

(25)
$$+ \int_a^\infty \frac{H'_\alpha(t) + H'_k(t)k_\alpha(t)}{H(t)} c^F(t)[1+\Phi(z(t))]S(t,a)dt$$

In (25) $k_\alpha(t)$ is the change in health care expenditure at age *t*. If health expenditures are chosen efficiently then terms involving $k_\alpha(t)$ vanish because the net return to a marginal increase in expenditure is zero. Then the balance of benefits and costs is surely positive and (25) is equivalent to (15). But the presence of third-party payers for medical services can distort these decisions, so the true benefits of medical advances can be smaller than the costs of supplying them. This can be important on certain margins, as when large medical costs are incurred very near the end of life, allegedly to little benefit.

Our empirical analogue of (25) compares the value of increased longevity to changes health expenditures, broken out by gender and age. We use data on individuals' expenditures from the Medical Expenditure Surveys, collected in 1977, 1987, and then as a panel starting in 1996. As is the case with virtually all survey estimates of household consumption, survey-predicted aggregate medical expenditure underestimates actual national expenditure for medical services. So we use the age profile of relative expenditures from the survey data to allocate total medical expenditures. This procedure gives us estimates of aggregate health care expenditure by age and gender from 1970 to 2000.[28]

Table 6 shows that medical expenditures grew from 11.3% of total consumption in 1970 to 19.6% in 2000. Adjusting real per-capita expenditures for the changing age composition of the population, per-person expenditure on medical services grew from $2171 in 1970 to $4855 in 2000, or by 124%. Calculating the present value of aggregate medical expenditures using 2000 population weights and survival probabilities, and assuming that the same level of expenditure applies to future years and birth cohorts, the capital value of medical expenditures grew from $16.2 trillion in 1970 to over $50 trillion by 2000.

Table 7 calculates net social gains from increased longevity by combining the estimates from Tables 5 and 6. It is important to note that this method of allocating benefits and costs is only a rough analogue of equation (25). In (25), $k_\alpha(t)$ represents the change in

[28] If the understatement varies by age, then our allocations will be biased. Based on data from national health care systems in Canada and the UK, the age profile of expenditures in the MES and MEPS is flatter than in these systems, suggesting that we might understate spending at older ages. However, MES and MEPS projections account for about 62 percent of total medical spending but 68 percent of actual Medicare expenditures, for which virtually all Americans over age 65 qualify. These data suggest that the actual age profile of medical spending is flatter in the US.

medical expenditures that are the direct consequence of implementing a new medical technology. We actually measure the value of increased longevity and changes in medical expenditures from all sources. This may cause us to either overestimate or underestimate the true social value of health care advances. First, changes in medical expenditures include expenditures that raise the "quality" of life ($H_\alpha(t) > 0$), which we ignore, so we may underestimate true social gains. Second, some current medical expenditures are investments in health that produce *future* benefits, so costs incurred in one period may yield measurable benefits later. Expenditures during our period of study may yield future benefits, leading to an underestimate of net gains, or benefits that we observe may be the outcome of past events, which causes an overestimate. Finally, some observed gains may be due to things unrelated to direct medical spending—for example cleaner air or water. We don't count the costs of these things.

With these caveats in mind, Table 7 shows our estimates of "net" social gains. Between 1970 and 2000 increased longevity yielded a "gross" social value of $95 trillion, while the capitalized value of medical expenditures grew by $34 trillion, leaving a net gain of $61 trillion—still large by any standard. Almost two thirds ($39 trillion) of this gain "occurs" in the 1970s, where both gross benefits are highest and additional costs are lowest. Overall, rising medical expenditures absorb only 36% of the value of increased longevity.

The estimates in Table 7 represent a sort of "average" gain over the population as a whole. Yet many critiques of the efficacy of rising medical expenditures focus on marginal decisions to expend resources when benefits are smaller than costs (e.g Meltzer, 2003), especially on life-extending procedures for individuals who are near death.[29] Table 8

[29] For example, over a quarter of all Medicare expenditures are spent in the last year of life, a proportion that has remained remarkably stable since the 1970s. See Hogan, Lunney, Gabel, and Lynn (2001)

provides some evidence on how our estimates of average net gains vary with age. For men, net gains are positive overall and in each sub-period for all but the oldest (85+) age category. Our estimate of incremental costs as a proportion of gross benefits is fairly constant until we reach older age categories (65 and older), when the cost share rises sharply. Women present a different story. Women's incremental costs are a larger proportion of benefits in every age group, and we estimate negative average net benefits for women over age 65. We estimate average net *losses* for women in almost every age group in the 1990s. In other words, even on average for these periods the value of women's longevity gains has not offset the rising costs of medical care.

What's on the Table? Prospective Gains from Medical Progress

We now turn to estimates of what can be gained from future progress against particular mortality-causing diseases. Our calculations make no attempt to deduct prospective costs of such progress, so they should be interpreted as the value of life-years that could be gained from a given reduction in mortality from a disease. This value must be large enough to cover the costs of developing and implementing new medical advances that would save lives.

Our benchmark is a 10 percent reduction in mortality from a life-threatening disease; this or even greater progress seems within the realm of possibility. Figures 9a and 9b show our estimates of the age profiles of individual values resulting from a 10 percent reduction in mortality from five major causes of death. For both men and women the largest potential values are for cardiovascular diseases, with peak gains occurring in late middle age at nearly $35,000 per person for men and $30,000 for women. Potential gains from progress against cancer are nearly as large, with a noteworthy earlier peak for women that reflects the incidence of breast cancer. Progress against infectious diseases—of which mortality from AIDS accounts for about a third—has lower average value because of much lower incidence, and it peaks earlier reflecting the typical age of onset.

The profiles in Figures 9a-b give values of progress at different ages. To get the current social value of such progress we aggregate over the age distribution of the 2000 U.S. population and add the present value of gains measured at birth for forecasted future birth cohorts, as in (25). These social values are shown in Table 9. A 10 percent reduction in all-cause mortality would have a present discounted social value of $18.5 trillion. About 30 percent of this total ($5.7 trillion) is due to potential progress against cardiovascular diseases, where much progress has already been made. Similar progress against cancer would be worth $4.7 trillion, with roughly equal benefits for men and women. A ten percent reduction in mortality from infectious diseases, including AIDS, is of roughly the same value to men ($500 billion) that progress against breast cancer would be for women ($444 billion). For women, progress against heart disease is four times more valuable than equivalent progress against breast cancer.

To put these values in perspective, total federal support for health related research in the United States for fiscal 2005 is about $28 billion. If we capitalize this expenditure over the indefinite future at 3 percent interest, it is roughly equal to the $1 trillion value of a *one* percent reduction in mortality from cancer and cardiovascular disease. Even if we offset these gains by substantial increases in the cost of the treatments required to implement potential new technologies, potential net gains would still be very large.

Our discussion of equation (19) indicated that forms of health progress are complementary—reductions in mortality from any source raise the value of further progress. The right hand column of Table 9 illustrates the importance of this effect by calculating the impact of 1970-2000 health progress on the prospective values from Panel A. The estimates show the increase in the current social value of *future* progress against each disease that is due to the decline in mortality between 1970 and 2000. Formally we calculate:

(26) $$\Delta W_\alpha = \int_{a=0}^{\infty} \{N^1(a)[V_\alpha^1(a) - V_\alpha^0(a)] + V_\alpha^0(a)[N^1(a) - N^0(a)]\}da$$

The social value of health complementarity has two components. The first is how much more *today's* population (N^1) will pay for future progress when that value is based on current survival rates (denoted V_α^1) than on past ones (V_α^0). The second component reflects the fact that today's population (N^1) is larger than had people lived their lives under mortality rates from 1970 (N^0).

Overall, we find that declining mortality between 1970 and 2000 raised the social value of future health progress by 18 percent, or by \$3.3 trillion for our benchmark case of a 10 percent reduction in death rates. Two-thirds of this effect (\$2.2 trillion) is due to increased willingness to pay for progress against heart disease and cancer. This illustrates that the value of health progress will continue to rise simply because people are getting healthier, even in the absence of growing productivity and incomes. Economic growth and income-elastic willingness to pay for health progress will only reinforce this effect.

Notice that the share of value attributed to complementarity is larger for diseases whose incidence increases with age. This is implied by equation (19) because reductions in mortality between 1970 and 2000 have mainly occurred at older ages, which has a stronger impact in raising the value of progress against age-related causes of mortality.

Changes in the Quality of Life

All of our calculations to this point have placed a value on actual and prospective changes in the quantity of life (longevity), ignoring possible gains in the quality of life through improvements in type-*H* health. This is simply because changes in mortality are directly measurable, while changes in the quality of life are not. Though we have no direct measure of these improvements, we think it's important to provide at least a ballpark estimate of how valuable these gains might be.

As a rough approximation we assume that advances in longevity and quality of life are related. Let $\lambda_0(t)$ and $\lambda_1(t)$ denote mortality rates at age *t* in 1970 and 2000, respectively. Since mortality rates declined, we assume that if $\lambda_1(t) = \lambda_0(t-k)$ then persons of age *t* in 2000 are *k* years "younger" than were similarly aged people in 1970. We then assign $H'(t)/H(t) = \ln H(t-k) - \ln H(t)$ based on the profile in Figure 2b, and we calculate the second term of (15):

(28) $$\int_a^\infty \frac{H'_\alpha(t)}{H(t)} c^F(t)[1+\Phi(z(t))]S(t,a)dt$$

Figure 10 shows estimates of the value of changes in type-*H* health based on this procedure for men and women aged 20 and over in 2000.

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Figure 1
Life Expectancy at Birth and Age 50
United States, 1900-2000

Source: National Vital Statistics Reports, vol 52, #14, February 18, 2004, Table 12.

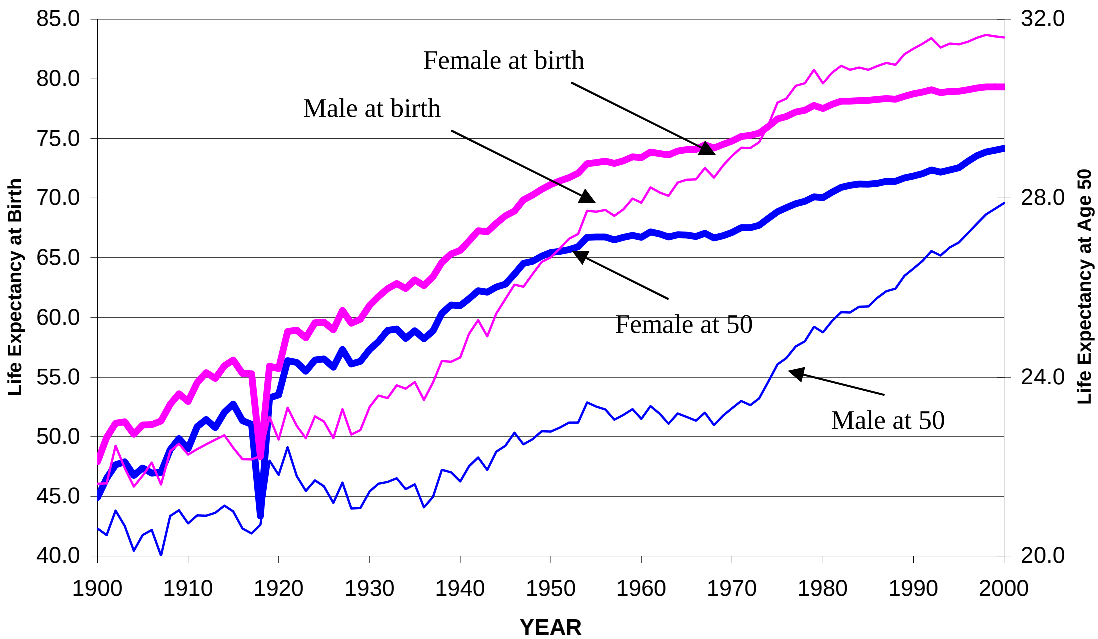


Table 1
Age Distribution of Increasing Longevity, by Decade, 1900-2000
(Additional expected life-years due to reduced mortality in each age interval)

Men

Age Interval	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000	Total
<1	1.90	2.48	1.63	0.97	1.66	0.54	0.36	0.75	0.23	0.19	10.71
1-14	1.51	1.00	1.37	1.04	0.65	0.17	0.10	0.13	0.10	0.09	6.16
15-34	0.68	0.16	0.96	0.99	0.71	0.18	-0.27	0.18	0.09	0.38	4.06
35-54	0.18	0.71	0.02	0.55	0.76	0.30	-0.02	0.67	0.32	0.37	3.87
55-74	0.02	0.45	-0.21	0.09	0.49	0.10	0.05	1.00	0.82	1.01	3.83
75+	0.02	0.05	0.05	-0.03	0.31	0.05	0.16	0.18	0.28	0.57	1.61
Total	4.31	4.85	3.83	3.62	4.57	1.33	0.37	2.92	1.85	2.60	30.25

Women

Age Interval	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2000	Total
<1	1.65	2.22	1.28	0.88	1.39	0.40	0.35	0.59	0.22	0.16	9.12
1-14	1.67	1.02	1.47	0.99	0.62	0.15	0.10	0.11	0.07	0.06	6.26
15-34	1.11	-0.57	1.62	1.24	1.00	0.30	-0.01	0.16	0.06	0.08	4.99
35-54	0.66	0.03	0.63	0.83	1.01	0.48	0.02	0.56	0.28	0.05	4.56
55-74	0.20	0.17	0.29	0.62	1.20	0.70	0.43	0.71	0.29	0.36	4.97
75+	0.02	0.02	0.16	0.03	0.66	0.23	0.73	0.80	0.34	0.09	3.07
Total	5.31	2.89	5.46	4.59	5.87	2.25	1.61	2.94	1.25	0.79	32.97

Notes: Figures are additional expected life-years calculated from *cross sectional* age-specific mortality rates in each year. Entries for each age interval are contributions to additional expected life years over the decade due to changes in mortality rates in that age interval. *Source:* Authors' calculations from Center for Disease Control, *Vital Statistics*, *Special Reports*, various years.

Table 2
Additional Life Years Due to Reduced Mortality From Selected Causes, by Decade, 1950-2000

Men

Disease	1950-60	1960-70	1970-80	1980-90	1990-00	Total
Infant Mortality	0.54	0.36	0.75	0.23	0.20	2.07
Heart Disease	0.16	0.38	1.05	1.26	0.88	3.73
Cancer	-0.19	-0.17	-0.08	0.02	0.43	0.01
Stroke	0.10	0.15	0.41	0.24	0.08	0.98
Accidents	0.18	-0.15	0.37	0.41	0.17	0.98
Other	0.54	-0.19	0.41	-0.31	0.85	1.30
Total	1.33	0.37	2.92	1.85	2.60	9.07

Women

Disease	1950-60	1960-70	1970-80	1980-90	1990-00	Total
Infant Mortality	0.40	0.35	0.59	0.22	0.13	1.68
Heart Disease	0.59	0.72	0.87	0.90	0.46	3.54
Cancer	0.20	0.07	-0.01	-0.11	0.17	0.31
Stroke	0.20	0.33	0.63	0.38	0.06	1.59
Accidents	0.10	-0.04	0.17	0.13	0.01	0.36
Other	0.77	0.19	0.69	-0.25	-0.04	1.36
Total	2.25	1.61	2.94	1.25	0.79	8.85

Notes: Figures are additional expected life-years calculated from *cross sectional* age-specific mortality rates in each year. Entries for each cause of death are contributions to additional expected life years over the decade due to changes in mortality rates from that cause. *Source:* Authors' calculations from Center for Disease Control, *Vital Statistics, Special Reports,* various years.

Table 3
Estimated Values of a Life-Year for 50 Year-Old Men

$$y^F + c^F \Phi(z) = y^F + c^F \frac{1}{\sigma - 1}[1 - \sigma(\frac{z_0}{z})^{\frac{\sigma-1}{\sigma}}]$$

	Elasticity of Intertemporal Substitution (σ)					
z_0/z	**1.2**	**1.1**	**1.0**	**.9**	**.8**	**.7**
.05	$282	$314	$360	$426	$535	$731
.10	$229	$249	$276	$314	$373	$471
.20	$169	$180	$193	$211	$237	$278

Note: The table assumes a value of full consumption of $y^F = c^F = \$120,000$ for a 50 year-old male with 4000 total available hours per year and wage of $30/hour, including benefits.

Figure 2a: Lifecycle Profiles of Full Income, Full Consumption and the Value of a Life-Year

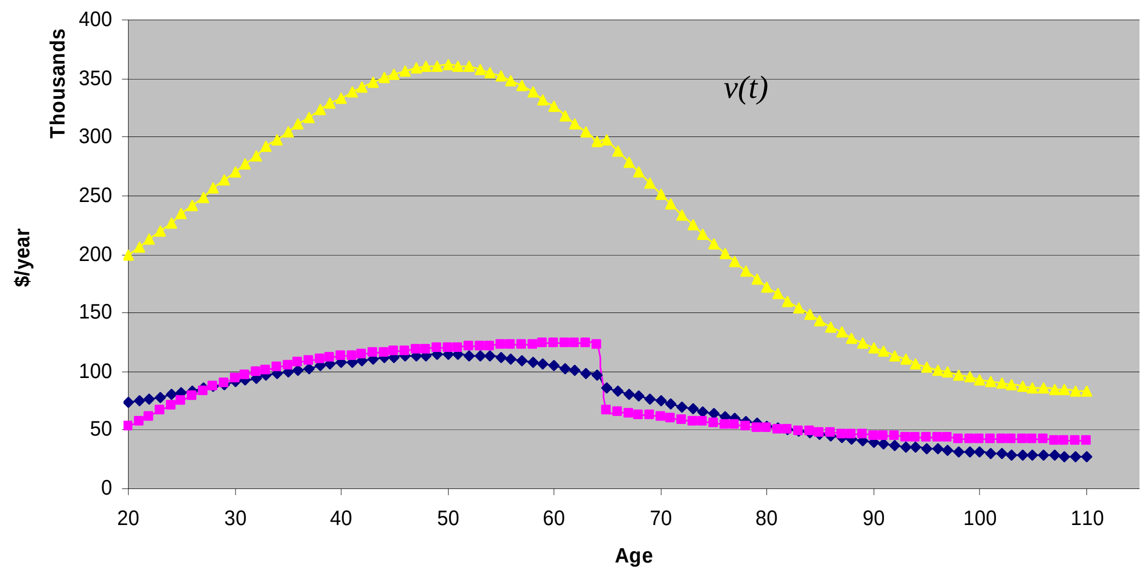
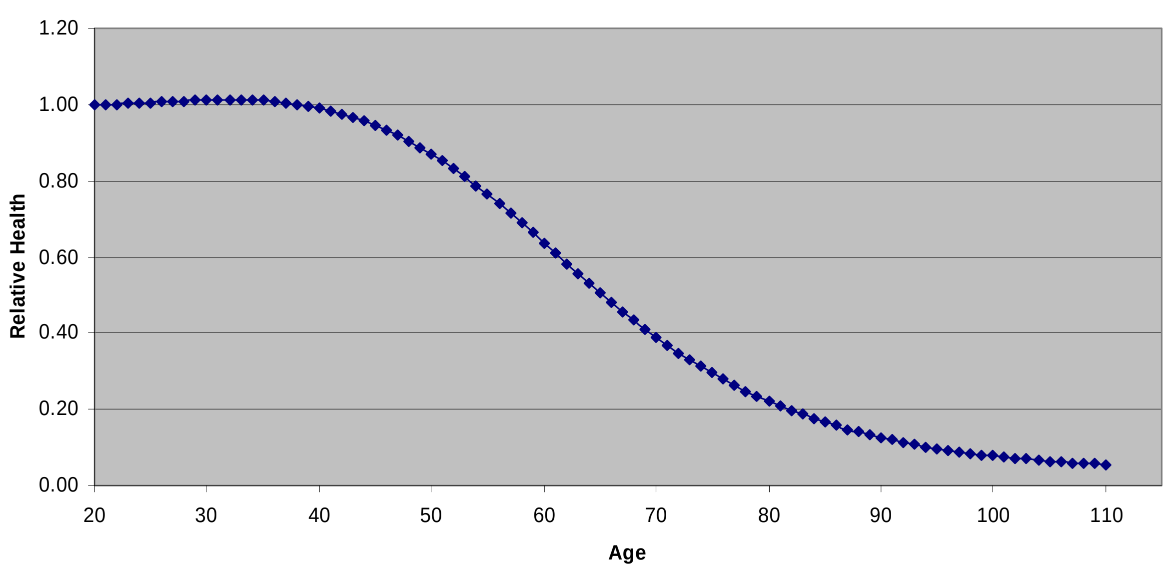


Figure 2b: Implied Shape of H(t) Consistent with Consumption Data



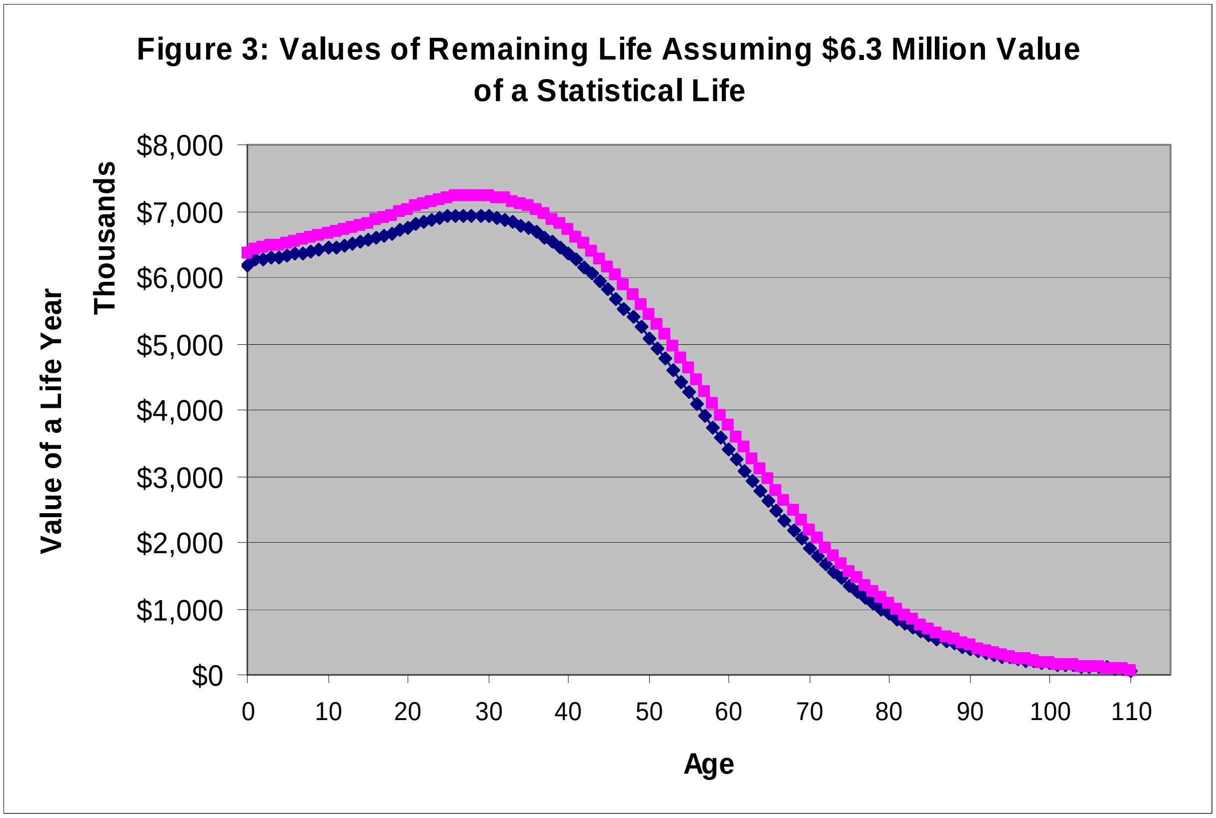


Figure 3: Values of Remaining Life Assuming $6.3 Million Value of a Statistical Life
Value of a Life Year
Thousands
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
0
10
20
30
40
50
60
70
80
90
100
110
Age

Figure 4a: Cumulative Values of Longevity Gains Since 1900: Men in 2000

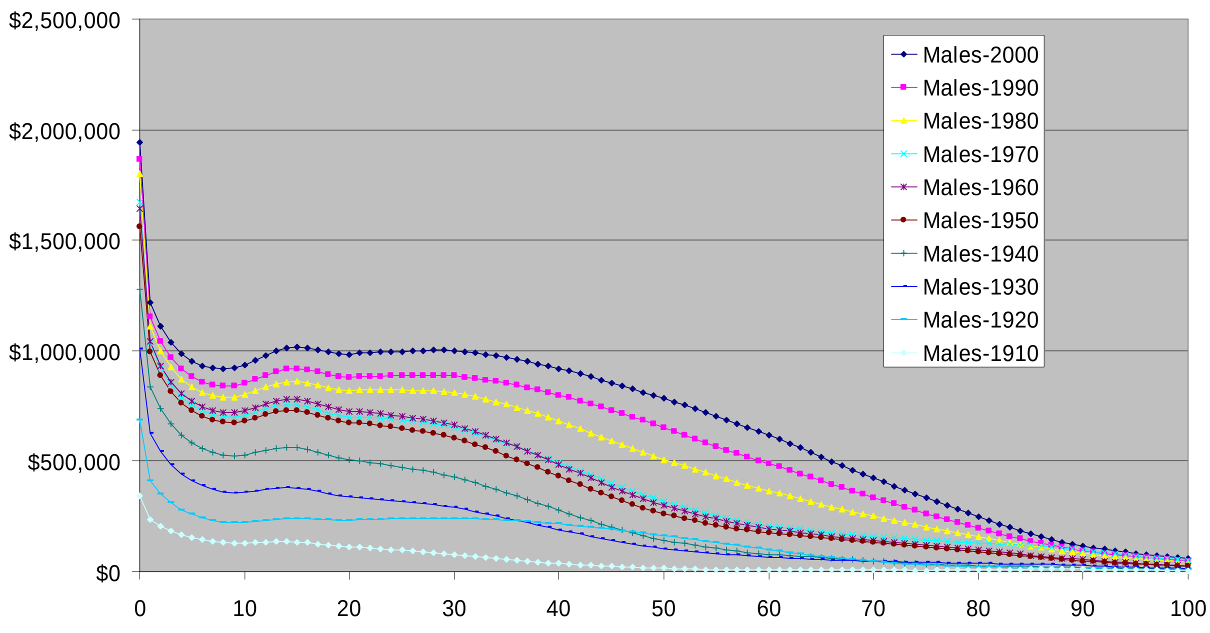
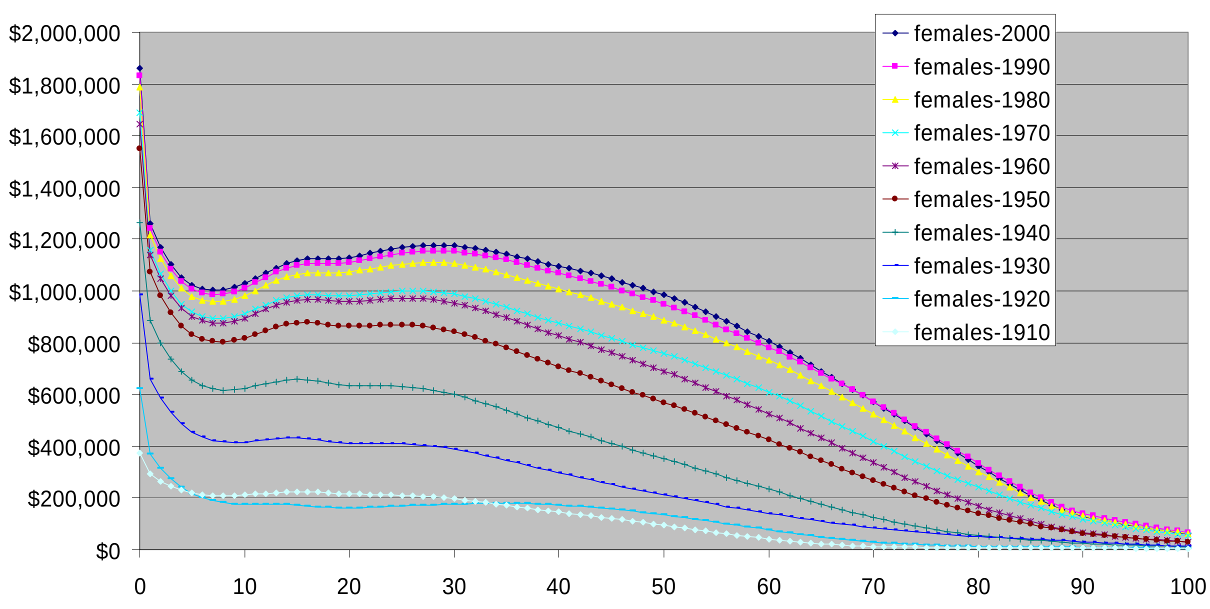


Figure 4b: Cumulative Value of Gains in Longevity Since 1900: Women in 2000



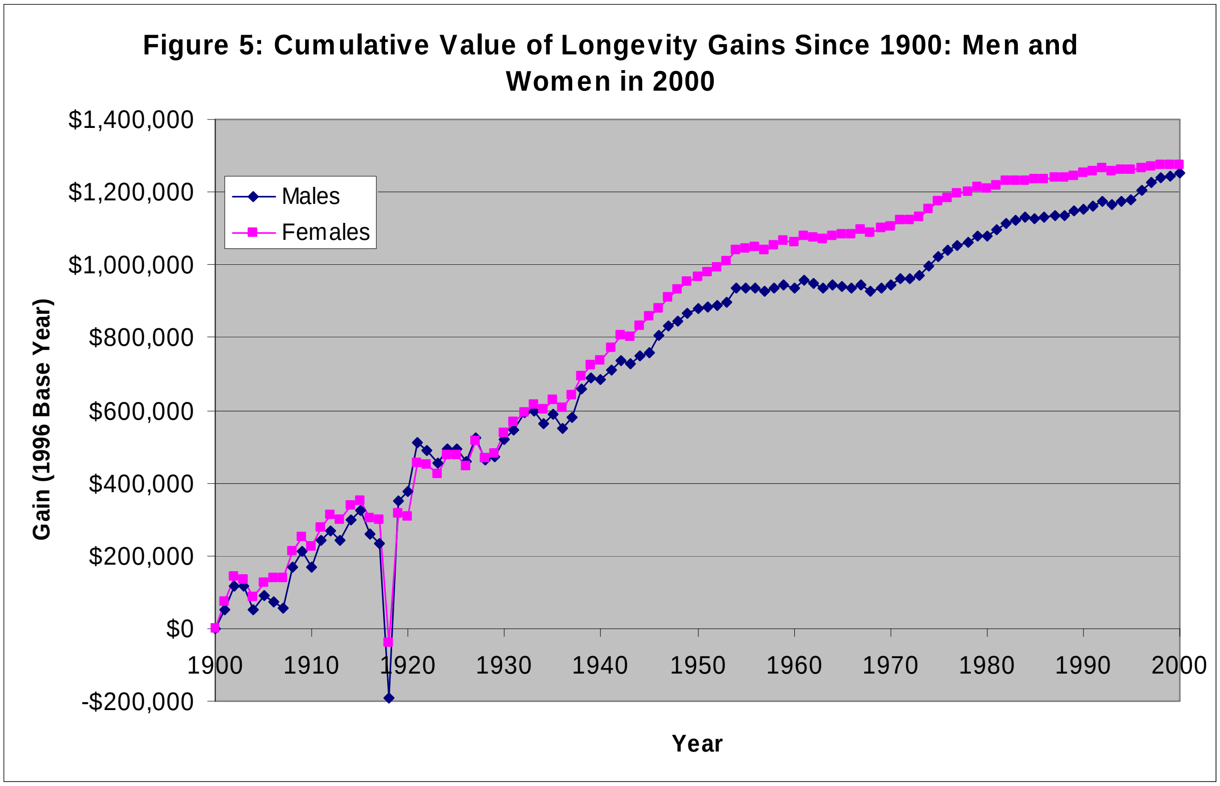


Figure 5: Cumulative Value of Longevity Gains Since 1900: Men and Women in 2000
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$0
-$200,000
Gain (1996 Base Year)
Males
Females
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

Table 4
Decade Averages of GDP and Production of Health Capital per Capita
1900-2000 ($2004)

	1900-10	1910-20	1920-30	1930-40	1940-50	1950-60	1960-70	1970-80	1980-90	1990-2000
GDP	$6,011	$7,239	$7,703	$7,578	$13,592	$15,856	$20,343	$25,342	$28,381	$32,057
Health Capital	$4,987	$2,754	$5,513	$6,062	$12,314	$4,951	$2,381	$12,839	$7,305	$8,240
Total	$10,998	$9,993	$13,216	$13,640	$25,906	$20,807	$22,724	$38,181	$35,685	$40,297
Share of Health Capital	0.45	0.28	0.42	0.44	0.48	0.24	0.10	0.34	0.20	0.20

Source: Author's calculations for health capital. GDP before 1929 from Kuznets (1961) as compiled by Jones and Obstfeld (2001), downloaded from NBER website. Post-1929 data from U.S. Department of Commerce, Bureau of Economic Analysis.

Figure 6a. Gains from Increased Longevity for Males 1970-2000

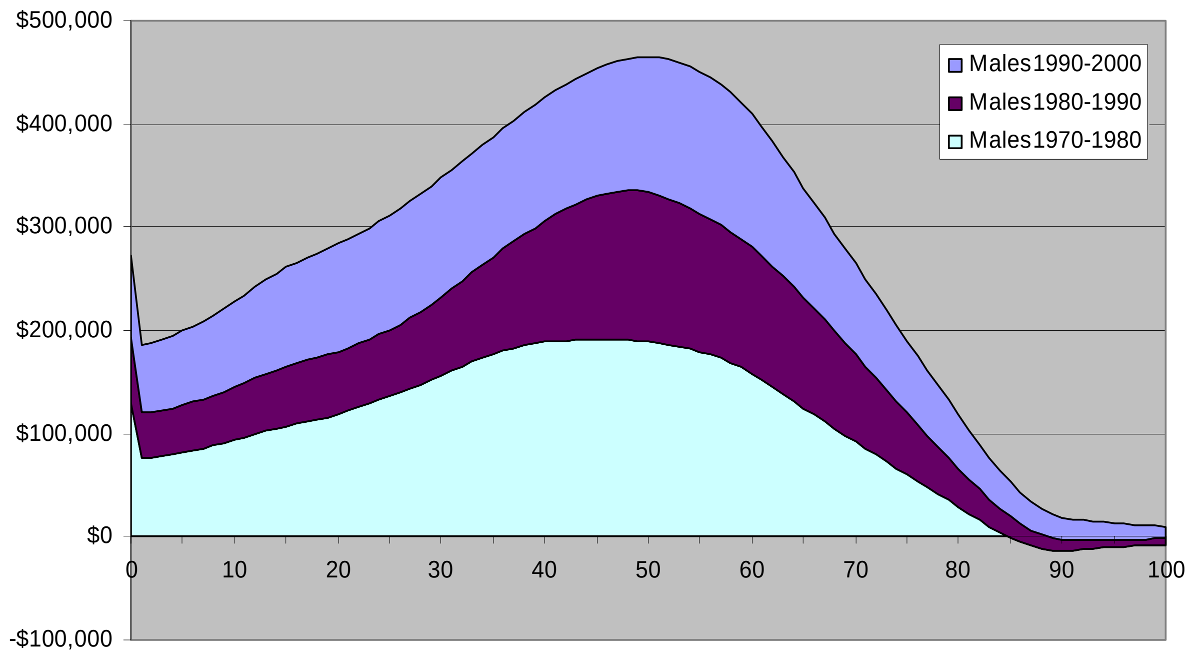
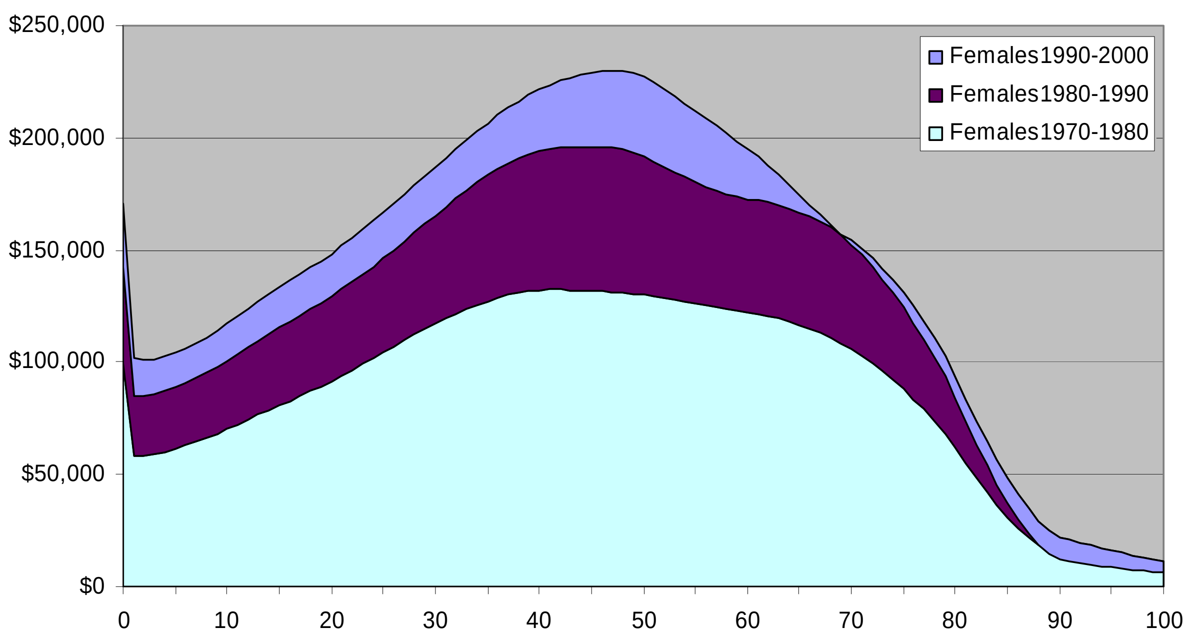


Figure 6b. Gains from Increased Longevity for Females 1970-2000



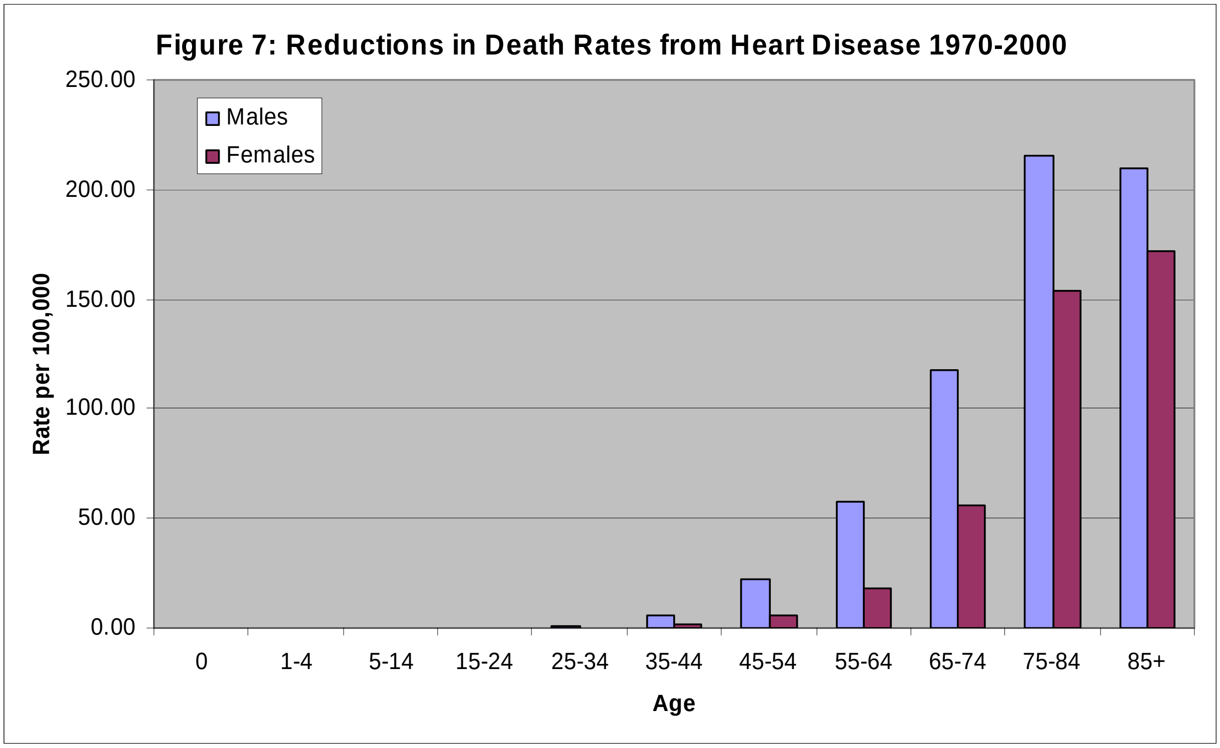


Figure 7: Reductions in Death Rates from Heart Disease 1970-2000
Males
Females
Rate per 100,000
250.00
200.00
150.00
100.00
50.00
0.00
0
1-4
5-14
15-24
25-34
35-44
45-54
55-64
65-74
75-84
85+
Age

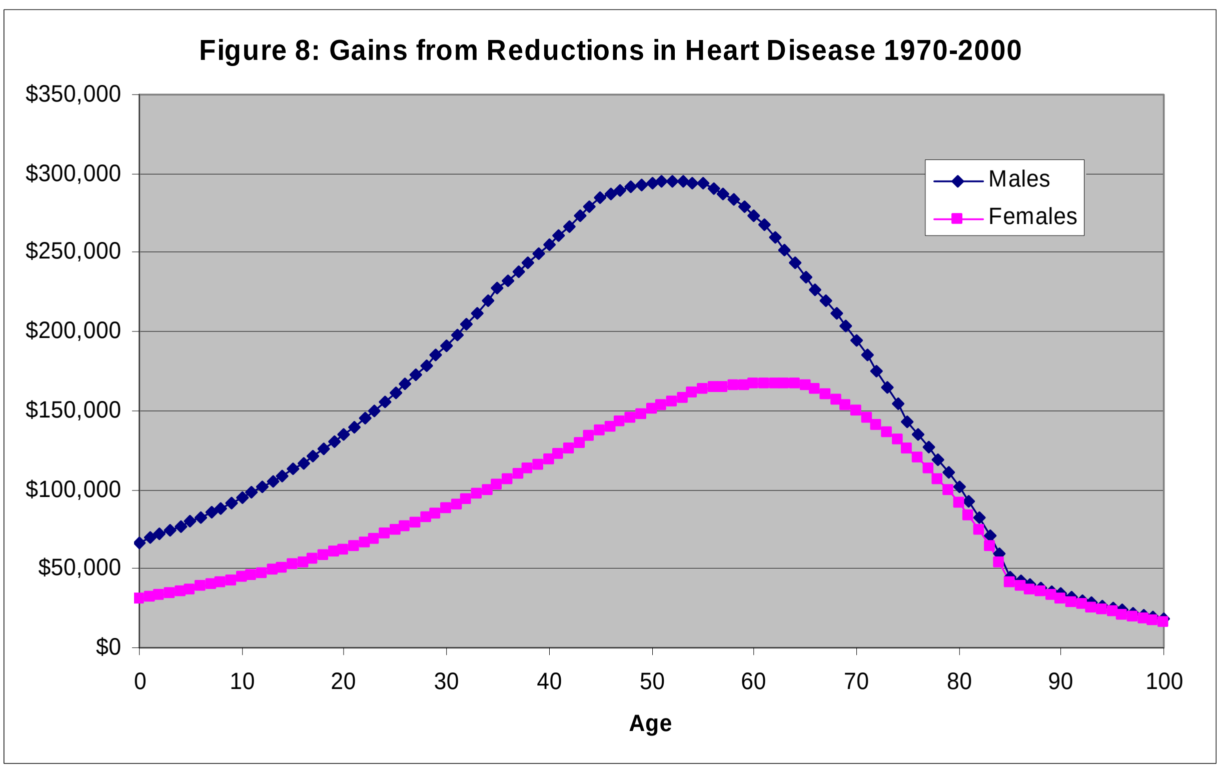


Figure 8: Gains from Reductions in Heart Disease 1970-2000
Males
Females
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
10
20
30
40
50
60
70
80
90
100
Age

Table 5
Economic Gains From Reductions in Mortality by Age and Overall

	Population	Gains Per Capita ($2004)			
Males	(1000)	**1970-1980**	**1980-1990**	**1990-2000**	**1970-2000**
Birth	72,134	$129,381	$62,904	$80,536	$272,821
1to4	7,938	$77,707	$44,446	$67,747	$189,900
5to14	19,681	$92,564	$50,912	$81,699	$225,175
15to24	18,618	$118,310	$60,553	$103,061	$281,925
25to34	20,191	$155,129	$76,181	$114,201	$345,511
35to44	21,569	$186,015	$114,368	$119,097	$419,481
45to54	15,836	$188,706	$142,098	$130,001	$460,805
55to64	10,166	$160,057	$123,566	$128,891	$412,514
65to74	8,325	$96,938	$87,575	$90,695	$275,207
75to84	4,486	$37,124	$43,542	$56,356	$137,022
85+	1,070	-$8,112	$14,405	$25,764	$32,057
Females		**1970-1980**	**1980-1990**	**1990-2000**	**1970-2000**
Birth	68,773	$99,375	$43,392	$27,808	$170,575
1to4	7,578	$59,139	$26,859	$15,649	$101,647
5to14	18,741	$69,415	$30,220	$16,407	$116,042
15to24	17,604	$90,711	$37,422	$19,168	$147,301
25to34	20,177	$115,916	$48,058	$21,755	$185,729
35to44	21,824	$131,014	$60,700	$27,032	$218,746
45to54	16,533	$130,033	$61,701	$34,326	$226,061
55to64	11,195	$122,529	$51,496	$23,018	$197,043
65to74	10,345	$106,297	$48,121	-$47	$154,370
75to84	6,944	$66,766	$33,786	-$8,995	$91,558
85+	2,692	$19,385	$11,524	-$10,213	$20,696

	Aggregate Gains (Billions of $2004)			
	1970-1980	**1980-1990**	**1990-20**	**1970-2000**
Males	$26,699	$15,471	$19,153	$61,323
Females	$20,515	$9,067	$4,440	$34,022
Total	$47,214	$24,538	$23,593	$95,345

Table 6
U.S. Health Expenditures 1970-2000

	1970	1980	1990	2000
Nominal Expenditures ($Billions)	$73	$246	$696	$1,311
% of Total Consumption Expenditures	11.3%	13.9%	18.2%	19.6%
Real Expenditures ($Billions 2004)				
Current Year Population	$261	$445	$812	$1,221
Fixed 1996 Population	$369	$548	$883	$1,143
Per Capita Expenditures ($2004)				
Current Year Population	$1,537	$2,354	$3,911	$5,187
Fixed Population	$2,171	$2,897	$4,249	$4,855
Present Value of Total Expenditures ($Billions 2004, Fixed Population)	$16,209	$24,414	$39,342	$50,933

Table 7
Estimated Gains Net of the Increase in Health Expenditures

	1970-1980	1980-1990	1990-2000	1970-2000
Gross Gains (from Table 5)	$47,214	$24,538	$23,593	$95,345
Increase in Expenditures	$8,206	$14,928	$11,591	$34,725
Gains Net of Expenditure Growth	$39,008	$9,611	$12,001	$60,620
Expenditure Increase as a % of Gains	17.4%	60.8%	49.1%	36.4%

Table 8
Economic Gains From Reductions in Mortality
Net of Increased Health Care Expenditure, 1970-2000

Males	Population	1970-1980	1980-1990	1990-2000	1970-2000	Pct.
Birth	72,134	$119,958	$38,551	$61,967	$220,477	19.2%
1to4	7,938	$68,373	$20,716	$49,657	$138,746	26.9%
5to14	19,681	$81,703	$23,746	$60,995	$166,444	26.1%
15to24	18,618	$105,116	$28,576	$78,704	$212,396	24.7%
25to34	20,191	$139,412	$39,890	$86,580	$265,882	23.0%
35to44	21,569	$167,199	$73,290	$87,865	$328,354	21.7%
45to54	15,836	$166,351	$97,230	$95,943	$359,524	22.0%
55to64	10,166	$133,497	$78,043	$94,456	$305,996	25.8%
65to74	8,325	$69,395	$46,002	$59,350	$174,747	36.5%
75to84	4,486	$16,138	$11,866	$32,473	$60,477	55.9%
85+	1,070	-$21,094	-$5,191	$10,989	-$15,296	147.7%

Females	Population	1970-1980	1980-1990	1990-2000	1970-2000	Pct.
Birth	68,773	$83,703	$14,249	$4,743	$102,695	39.8%
1to4	7,578	$43,537	-$1,779	-$7,009	$34,749	65.8%
5to14	18,741	$51,176	-$2,832	-$9,736	$38,608	66.7%
15to24	17,604	$68,355	-$2,117	-$12,086	$54,153	63.2%
25to34	20,177	$88,985	$2,131	-$14,513	$76,603	58.8%
35to44	21,824	$98,440	$7,395	-$15,017	$90,818	58.5%
45to54	16,533	$90,914	$1,438	-$13,128	$79,224	65.0%
55to64	11,195	$75,543	-$13,315	-$27,842	$34,386	82.5%
65to74	10,345	$54,837	-$17,060	-$51,047	-$13,269	108.6%
75to84	6,944	$20,825	-$24,405	-$54,526	-$58,107	163.5%
85+	2,692	-$17,106	-$34,698	-$46,378	-$98,182	574.4%

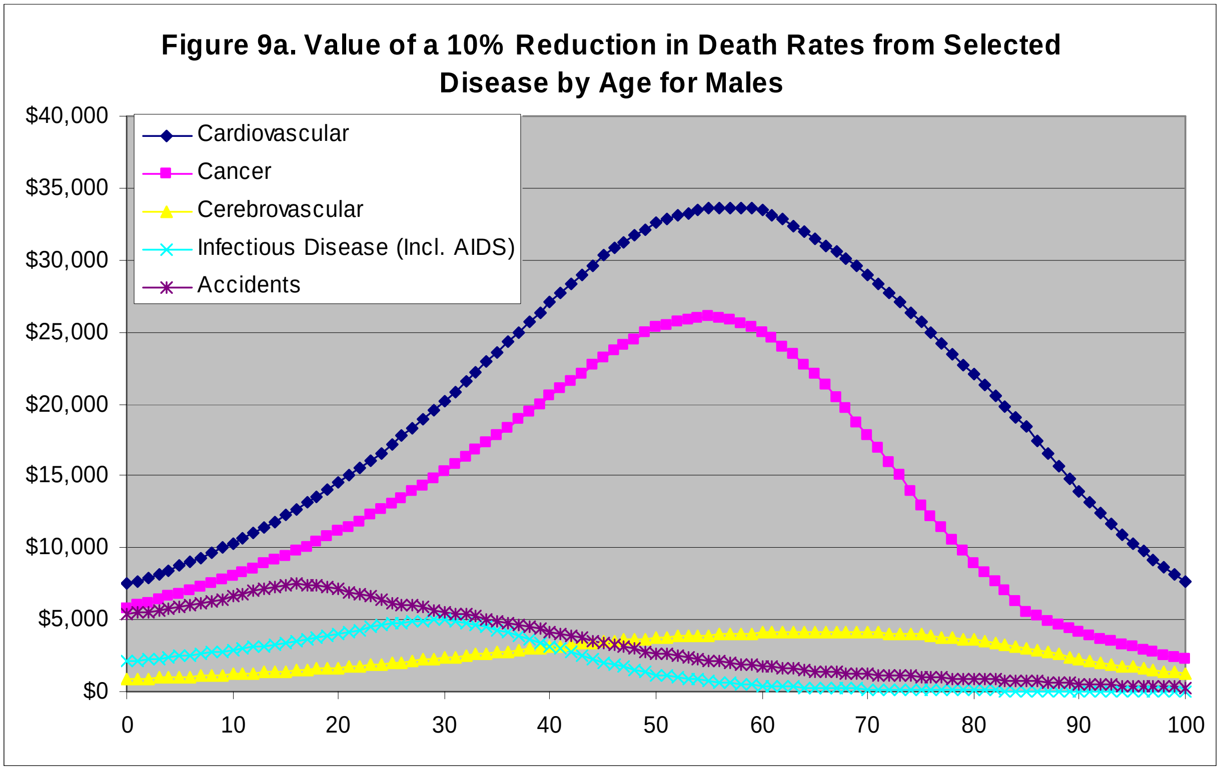


Figure 9a. Value of a 10% Reduction in Death Rates from Selected Disease by Age for Males
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
0
10
20
30
40
50
60
70
80
90
100
Cardiovascular
Cancer
Cerebrovascular
Infectious Disease (Incl. AIDS)
Accidents

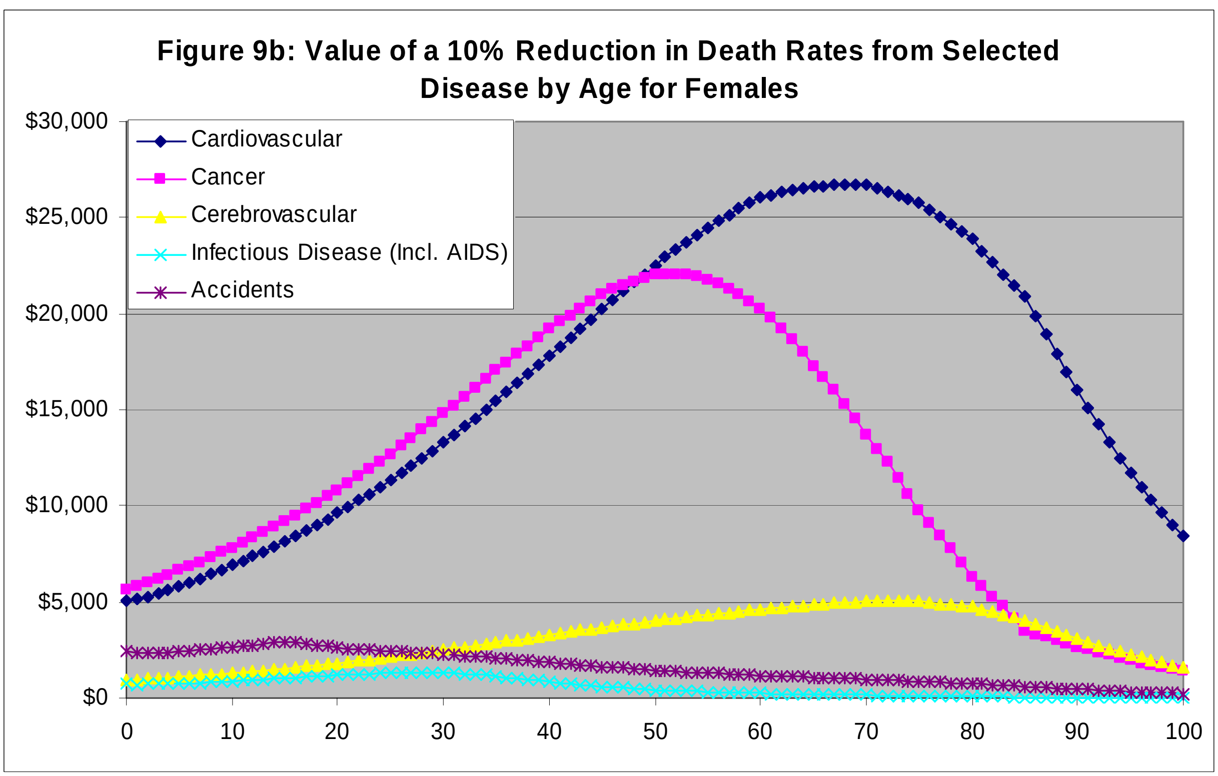


Figure 9b: Value of a 10% Reduction in Death Rates from Selected Disease by Age for Females
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
0
10
20
30
40
50
60
70
80
90
100
Cardiovascular
Cancer
Cerebrovascular
Infectious Disease (Incl. AIDS)
Accidents

Table 9
Current Value of a 10 Percent Reduction in Mortality from Major Diseases
(Billions of $2004)

Major Cause of Death	Males	Females	Total	Complementarity Effect	
				Value	Share
All Causes	$10,651	$7,885	$18,536	$3,278	0.18
Cardiovascular Diseases	$3,254	$2,471	$5,725	$1,288	0.22
Heart Disease	$2,676	$1,852	$4,529	$1,013	0.22
Cerebrovascular Diseases	$393	$460	$852	$194	0.23
Malignant Neoplasms	$2,415	$2,261	$4,675	$863	0.18
Respiratory & Intrathoracic	$847	$557	$1,404	$278	0.20
Breast	$3	$444	$447	$51	0.11
Genital & Urinary	$301	$302	$603	$126	0.21
Digestive Organs	$575	$431	$1,006	$200	0.20
All Other Infectious Diseases	$500	$148	$649	$60	0.09
Obstructive Pulmonary Disease	$343	$331	$674	$153	0.23
Pneumonia & Influenza	$214	$194	$408	$98	0.24
Diabetes	$237	$249	$486	$91	0.19
Liver Disease & Cirrhosis	$217	$102	$319	$46	0.14
Accidents & Adverse Effects	$977	$421	$1,398	$133	0.10
Motor Vehicle Accidents	$519	$247	$767	$62	0.08
Homicide & Legal Intervention	$324	$90	$415	$29	0.07
Suicide	$411	$102	$513	$50	0.10