The Economic Value of Medical Research

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Abstract

Basic research is a public good, for which social returns may greatly exceed private ones. This paper develops an economic framework for evaluating the social benefits of medical research. We begin with a model of the economic value of health and life expectancy, which we apply to US data on overall and disease-specific mortality rates. We calculate (i) the social value of increased longevity that took place from 1970 to 1990 and, (ii) the social value of potential future progress against various major categories of disease. The historical gains from increased longevity have been enormous, on the order of $2.8 trillion annually from 1970 to 1990. The reduction in mortality from heart disease alone has increased the value of life by about $1.5 trillion per year over the 1970 to 1990 period. The potential gains from future innovations in health care are also extremely large. Eliminating deaths from heart disease would generate approximately $48 trillion in economic value while a cure for cancer would be worth $47 trillion. Even a modest 1 percent reduction in cancer mortality would be worth about $500 billion. Unless costs of treatment rise dramatically with the application of new medical knowledge, these estimates indicate that the social returns to investment in new medical knowledge are enormous.

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I. Introduction

The United States invests over $35 billion annually in medical research. Federal support accounts for about 38 percent of this total, and private industry about half; the rest comes from various public and private sources. Federal support of medical research has also grown substantially: between 1986 and 1995 real federal expenditures on medical research increased by 46 percent, reaching $13.4 billion annually.[1] This is more than one-fifth of federal outlays on research and development.

As these figures indicate, the US invests substantial public and private resources in maintaining and improving the health of its population.[2] Are these expenditures warranted? Do we invest enough? The answers are non-trivial because medical knowledge, once produced, is a public good whose benefits can be enjoyed by all. Yet even with the substantial public expenditures indicated above, the social benefits from greater investment in medical knowledge may far outstrip costs, so that current investment is too low. Whether in fact it is too low is the empirical issue that we take up.

This paper begins an analysis of the social returns to health related research. We begin by addressing a broader question: What is the economic value of improvements in health and life expectancy? Armed with a suitable economic framework for this problem, we are able to estimate the economic value of the changes in life expectancy observed over the past several decades. Our results imply that the economic value of these gains has been enormous. We estimate that improvements in life expectancy alone added approximately

[1] Over the same period, real per-capita annual spending on health care roughly doubled, from $1,360 per person in 1980 to $2771 in 1995. Health care spending also increased as a share of total spending; total spending on health care accounted for about 16% of personal consumption expenditures in 1995 versus 10% in 1980 and only 8% in 1970.

[2] Comparison to other OECD

$2.8 trillion *per year* (in constant 1992 dollars) to national wealth between 1970 and 1990. For comparison, real GDP for 1980 (the midpoint of the period) was about $4.6 trillion, so the flow of *uncounted* additions to national wealth due to rising longevity was more than half of measured GDP in a typical year.

While some of the growth in life expectancy is due to factors other than improvements in health care or medical knowledge, narrowly defined, the magnitudes of overall gains suggest that the contributions of improved health care and medical knowledge are similarly large. Indeed, we estimate that more than half of the $2.8 trillion annual value of increasing longevity can be attributed to declining mortality from heart disease, for which medical advances are known to be significant (see Cutler & Richardson 1997).

More important than these historical gains, our analysis also demonstrates that the prospective value of further improvements in health care is large. For example, we estimate that curing heart disease would generate about $48 trillion in economic value while eliminating deaths from cancer would be worth $47 trillion. One might argue that such dramatic improvements in health are not on the immediate horizon. Yet our calculations mean that even a 1 percent permanent reduction in mortality from cancer would be worth about $500 billion. To put this value in perspective, consider a federal commitment of an additional $100 billion for cancer research to be spent, say, over the next 10 years. Such a program entails a 75 percent increase in federal expenditures on medical research, with *all* of the increase devoted to a single disease. Our estimates imply that the program would be worthwhile if it had only a one-in-five chance of producing a 1 percent reduction in cancer mortality, and a four-in-five chance of producing nothing.

The economic gains from increasing life expectancy are rising over time. We show that the economic return to improvements in health are 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 a rising value 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 ages toward the primary ages of disease-related death, the economic reward to improvements in health will continue to increase. We find that the growth and aging of the population alone will raise the economic returns to advances against many diseases by almost 50% between 1990 and 2030. Projected increases in real incomes and life expectancy will add at least that much again

Our analysis highlights some of the interesting 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 (Social Security, private pensions, Medicare and private medical coverage) and the prevalence of third party payers increase the incentive to spend on medical care. These distortions also skew investments in research away from cost-decreasing improvements in technology. In the presence of such distortions, we must take account of the induced effect that research has on expenditures when evaluating the social returns to improvements in technology. Our methodology does this.

We also show that improvements in health are complimentary with one another – for example, improvements in life expectancy (from any source) increase the economic value of further improvements by raising the value of remaining life. This means that advances against one disease, say heart disease, raise the economic value of progress against other diseases, such as cancer. 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 economic returns to research on cancer and other diseases.

While our results strongly suggest that the economic return to medical research is high, we do not assign numerical values to the changes in longevity and health that are due to research advances. So some of the paper is devoted to laying out a research plan that can lead to more definitive results. The plan divides the problem into steps. The first step is to isolate the impact of improvements in health care on health and life expectancy by disease category over time. These improvements can then serve as measures of the "outputs" of the health care system. The difference between the growth in health system "outputs" and health system "inputs" is a measure of the rate of technological progress or growth in total factor productivity [TFP]. TFP growth can then be linked to investments in medical R&D to determine the social product of medical research. This approach is not unique; rather it follows the "standard" economic methodology for estimating the social value of R&D (see Griliches and Lichtenberg, 1984).

The paper is organized as follows. Section II outlines our economic model for valuing improvements in health and life expectancy. We illustrate how value-of-life estimates can be applied to the problem at hand. We also develop our methodology for relating the increase in life expectancy to improvements in medical technology, and identify the key determinants of the economic return to improved health. Section III presents estimates of the economic gains associated with past improvements in life expectancy, as well as prospective estimates of the value of progress against several major categories of disease. Section IV provides a preliminary evaluation and analysis of the returns to medical research while section V outlines proposals for a more detailed analysis.

II. A Framework for Valuing Improvements to Health and Longevity

Improvements in health and medical knowledge affect the quality of life and the risks of mortality at various stages of the lifecycle. How much are people willing to pay for these improvements? We follow Rosen (1988) by assuming that willingness to pay is determined by the expected discounted present value of lifetime utility.[3] Write lifetime discounted utility for a representative individual at age *a* as

$$U(a) = \int_a^\infty H(t)u(c(t),l(t))S(t,a)dt \tag{1}$$

In (1) *H(t)* is "health," so we assume that improvements in health raise instantaneous utility from consumption, *c(t)*, and non-market time, *l(t)*. *S(t,a)* is the "discounted survivor function":

[3] Rosen's (1988) setup is similar to ours, but it does not result in empirically tractable formulae for valuing changes in longevity. Our equation (11), below, incorporates estimates of the value of nonmarket time and the value of improvements to health while living in assessing the value of medical advances.

(2) $$S(t,a) = \exp[-r(t-a) - \int_a^t l(t)dt]$$

which reflects both time preference (r) and mortality risks via the time-varying instantaneous hazard function $l(t)$. If $r = 0$ then $S(t,a)$ is just the probability that the agent survives from age a to t. To economize on notation we do not specify variables that shift the hazard; an obvious factor is health itself, where we expect $l'_H(t) < 0$ so that improvements to health reduce the per-period probability of dying. But it is also reasonable to think of situations where mortality is changed without improvements in health, as when safety improvements reduce the likelihood of industrial accidents.[4] At a more fundamental level we expect that health and mortality are determined by the stock of medical knowledge, the availability of health care that applies medical knowledge, public health infrastructure, and private decisions. These are taken up below.

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

(3) $$\frac{\partial S(t,a)}{\partial q} \equiv S'_q(t,a) = -S(t,a)\int_a^t l'_q(t)dt$$

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

[4] Likewise, medical innovations can change health without changing mortality. Orthopedic advances such as hip replacements and artificial knees are examples.

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

$$(4) \qquad \int_a^\infty c(t)S(t,a)dt = A(a) + \int_a^\infty y(t)S(t,a)dt$$

where *A(a)* is initial assets at age *a* and *y(t)* is income at age *t*. Equation (4) is the lifecycle equivalent of a complete market for consumption insurance.

The individual must choose an optimal consumption profile to maximize (1) subject to (4). That is, the individual chooses *c(t)* to

$$(5) \qquad \text{Max } U^*(a) = \int_a^\infty H(t)u(c(t),l(t))S(t,a)dt + m[A(a) + \int_a^\infty \{y(t) - c(t)\}S(t,a)dt]$$

The necessary condition for optimal consumption is

$$(6) \qquad H(t)u'_c(c(t),l(t)) = m$$

so the time paths of optimal consumption and nonmarket time equalize the marginal utility of consumption over the remaining lifecycle. Notice that health, *H(t)*, and consumption of other goods are natural complements in our setup. For example, if health declines at older ages, (6) implies that consumption will decline as well.

Equation (5) is our basic building block for thinking about factors such as medical knowledge that provide value by extending lives or improving health. Before turning to those issues, however, notice that (5) and (6) provide a dollar figure for the "value of a life." Divide (5) by the constant marginal utility of consumption in (6):

$$(7) \qquad V(a) \equiv \frac{U^{*}(a)}{m} = \int_{a}^{\infty} [\frac{u(c(t),l(t))}{u_c'} + (y(t) - c(t))] S(t,a)dt + A(a).$$

The terms in brackets of (7) represent the contribution at age *t* to the dollar value of lifetime utility from increasing *S(t,a)*. This gain consists of instantaneous utility *u(c(t),l(t)) plus* net savings that accrue at age *t*. The latter term appears because savings at *t* are used to finance consumption in other periods, with marginal utility *m*. Topel and Welch (1986) refer to the integrand in (7) as "full utility": instantaneous utility from consumption and leisure, plus the utility-equivalent value of net savings.

Notice that health, *H(t)*, does not appear explicitly in the value of life formula (7). So, for example, think of two societies, *A* and *B*, with identical mortality – *S(t,a)* – and wealth, but where society *A* has uniformly greater *H(t)*. Equation (7) implies that the monetary value of a life will be the same in each society, so it appears that health has no economic value. This occurs because, in our setup, 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.[5] This does not mean that health has no economic value, however; it simply says that willingness to pay for changes in survival do not depend on the level of health.

Willingness to Pay for Improvements in Health or Longevity

To see this more clearly, consider some factor, q, that can affect both the health of agents and the probability of survival to any age t. For purposes of subsequent discussion we will refer to q as the stock of medical knowledge, which can be augmented through investments in research. But q could also represent expenditures on public health or increased availability of medical care. With this in mind, the marginal value of changing q follows from the displacement of (4):

[5] 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 $v'(H)/u_c(S,c)$.

$$(8) \qquad V_q'(a) = \int_a^{\infty} [\frac{u(c(t),l(t))}{u_c'} + y(t) - c(t)] S_q'(t,a)dt$$

$$+ \int_a^{\infty} \frac{H_q'(t)}{H(t)} \frac{u(c(t),l(t))}{u_c'} S(t,a)dt$$

The first line of (8) is the dollar value of the gain in lifetime expected utility from changes in mortality, indexed by changes in the survivor function $S_q'(t,a) \equiv \partial S(t,a)/\partial q$. These changes in the probability of survival weight the dollar value of full utility (utility plus net contributions to wealth) in each period. The second line of (8) represents the value of changes in health at each future age, $H_q'(t) \equiv \partial H(t)/\partial q$, that raise utility holding mortality fixed. Equation (8) measures changes in the "value of life" induced by changes in health and/or mortality. It is the foundation for our efforts to value the past and prospective contributions of medical research to health and longevity. To make headway with (8), however, we need to add slightly more structure.

The first term in (8) highlights the error in using income alone to value changes in mortality. The integrand can be rewritten as

$$y(t) + c(t)\left[\frac{u(c(t),l(t))}{cu_c'} - 1\right]$$

$$= y(t) + c(t)\left[\frac{1-e}{e}\right],$$

where $e = d\log u/d\log c$ is the elasticity of total utility with respect to consumption (Rosen 1988). Algebraically, $e < 1$ when the average utility of consumption exceeds marginal utility, yielding a consumer's surplus in each period of life.

There are two basic reasons for $e < 1$. First is the value of nonmarket time, or leisure, l(t). Suppose that utility is linear in $c(t)$ and $l(t)$, say $u_c c(t) + u_l l(t)$, so there is perfect intertemporal substitution in consumption and leisure. Then $e = c(t)/(c(t) + \frac{u_l}{u_c} l(t)$ is the "expenditure share" of $c(t)$. This share is smaller than unity so long as nonmarket time is valued ($u_l/u_c > 0$).

The second reason for $e < 1$ is that levels of consumption in different periods may not be perfect substitutes because average and marginal utilities of consumption are not the same. For example, let utility take the power function form $u(c, l) = c^e$, so that leisure has no value. Here $1 – e$ is the coefficient of relative risk aversion, $-cu''(c)/u'(c)$, with $e < 1$ when utility is concave. Then the timing of consumption "matters" in addition to income because the optimal consumption program equates marginal utilities at all ages.

We incorporate both of these effects in an empirically tractable specification of instantaneous utility. We assume that $u(c(t), l(t))$ is homogeneous of degree r, so that

(9) $$u(c(t), l(t)) = \frac{1}{r}[u'_C c(t) + u'_l l(t)]$$

We can think of $r \leq 1$ as an index of concavity in instantaneous utility. Using (9), the integrand in the first line of (8) becomes

$$\text{(10)} \qquad \frac{u(c(t),l(t))}{u_c'} + y(t) - c(t) \;=\; \frac{1}{r}[c(t) + \frac{u_l'}{u_c'} l(t)] + y(t) - c(t)$$

$$= y^F(t) + \Phi c^F(t)$$

where Φ = $(1\text{-}r)/r$ and

$$\text{(11)} \qquad \begin{aligned} y^F(t) &= y(t) + \frac{u_l'}{u_c'} l(t) \\ c^F(t) &= c(t) + \frac{u_l'}{u_c'} l(t) \end{aligned}$$

The expressions in (11) represent the "full" values of income (y^F) and consumption (c^F), both of which include the shadow value of non-market time consumed at age t. Using these relations and (3) yields the following expression for the change in the value of a life induced by dq:

$$\text{(12)} \qquad V_q'(a) \;=\; \int_a^\infty [y^F(t) + \Phi c^F(t)] S(t,a) [\int_a^t l_q'(t)dt] dt \;+\; (1+\Phi)\int_a^\infty \frac{H_q'(t)}{H(t)} c^F(t) S(t,a) dt$$

Implications for Valuing Health and Longevity

Equation (12) has a number of important implications for valuing changes in longevity and health.

1. The value of increased longevity ($S_q'(t,a)$) and health ($H_q'(t)$) are proportional to the levels of full income and full consumption, so willingness to pay rises with wealth. In a population, this means that wealthier people place greater value on additional life years, which we expect will be reflected in behavior. For example, our model predicts that wealthy individuals are less likely to smoke, and that they were more likely to quit smoking when the health consequences became well known. These predictions are consistent with patterns of smoking in the U.S.[6]

2. Full income and full consumption include the value of non-market time. "Value of life" calculations that focus solely on earned income will therefore understate willingness to pay for additional life years. This is particularly important in our analysis, where improvements in health and longevity may be concentrated at older, typically post-retirement, ages, when income is small. Then non-market time may be the most important determinant of willingness to pay.

3. The values of improvements in health and longevity increase with F. When $F = 0$ there is perfect intertemporal substitution in consumption (or leisure) – agents don't care *when* they consume – so there is no gain to reallocating consumption over time. With concave utility and fixed wealth, however, an increase in the survivor probability in any period yields a utility surplus: the expected utility of additional consumption and leisure,

$u(c,l)$, exceeds the opportunity cost of foregone consumption from other periods, *mc*. Then empirical application of the first terms in (12) requires knowledge of *both* the time paths of income and consumption, as well as knowledge of intertemporal substitution indexed by F, which determines the premium for consumption smoothing. We return to this point below.

4. Because future life years are discounted – due both to positive interest and mortality – the value of progress against a disease is greater the closer is current age, *a*, to the onset of the disease. For example, progress against Alzheimer's disease – which strikes older people – is of greater value to a 60 year-old than to a 25 year-old, for whom the disease is a distant possibility.

5. Reductions in mortality from any disease are more valuable the greater is $S(t,a)$, the probability of surviving to age *t*. This means that advances against distinct diseases – say heart disease and Alzheimer's – are complementary: A reduction in mortality from heart disease *raises* the value of advances against Alzheimer's because people are more likely to survive to old age. It also means that reductions in the hazard from a particular disease are more valuable in a society with greater longevity. Progress against Alzheimer's is of little value in Guinea Bissau because relatively few of its citizens reach old age, but it may be of great value in advanced countries where expected lifetimes are longer.

To this point our discussion has focused on the value of changed health or longevity at the individual level. The public good nature of medical knowledge (and many other

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[6] See National Center for Health Statistics, National Health Interview Survey, 1998, Table 63.h

factors that fit the rubric of (12)) implies that the gains in (12) will be realized by many. Formallyl, to calculate the *social* value of an increase in medical knowledge, we must aggregate over the current and expected *future* populations that benefit from such a change. Assume that (12) represents willingness to pay for a representative agent of age *a*. Then the marginal social value of a change in medical knowledge is

$$(13) \qquad W_q(t) = \sum_{a=0}^{\bar{a}} N(a,t)\, V_q'(a) + N^*(t)\, V_q'(0).$$

In (13), $N(a,t)$ is the population of age *a* at date t and $N^*(t)$ is the present discounted value of the number of births in future years. Equation (13) provides two additional implications for valuing changes in longevity and health:

6. The social value of an increase in life expectancy or health is proportional to the size of the population.

7. The social value of an increase in life expectancy or health is greater when the age distribution of the population is concentrated around (but before) the ages where the greatest reductions in death rates, or increases in health, occur.

These implications are useful for gauging the value of changed mortality and health in the United States. Over time the US population is aging, mortality from various diseases continues to decline, the population is growing, and income levels are rising. Each of these factors implies that the social value of improvements to health and longevity is higher than in the past, and is likely to grow over the next several decades. All else equal, these facts indicate that optimal expenditures on health-related research are increasing over time.

Calibrating the Model: The Value of a Life-year

Equation (12) contains two terms, one dealing with changes in mortality ($S_q'(\cdot)$) and the other with changes in health ($H_q'(\cdot)$). The remaining discussion will focus on changes in mortality, which is easier to measure; we return to the problem of measuring changes in health below.

To value changes in mortality using (12), we need information on the terms $y^F(t)$, $c^F(t)$, and F, along with estimates of the changes in survivor rates across ages. Survivorship data can be obtained from published mortality tables, broken down by various categories such as age, race, and sex. Reasonable estimates of lifecycle patterns of income and consumption can be garnered from survey data, but F is a structural parameter that must be estimated from compensation for observable risks. Our strategy for estimating F relies on estimates of "the value of a statistical life" taken from the literature on compensating wage differences for risks of job-related death (see Viscusi [1993] for a survey or Thaler and Rosen [1975] for an original analysis). Briefly, the value of a statistical life is derived from regression estimates of the wage premium that workers would demand in order to bear a, say, 1 in 10,000 greater annual probability of death from job-related causes. Suppose this premium is $500 per worker per year. 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. Thus the value of one statistical life in this is example is $5 million.

To calibrate the conceptual experiment in terms of our lifecycle model, suppose that workers make career choices of an occupation at time zero (say, age 20), after which there is no mobility among occupations. Different occupations involve different risks of job-related death, as indexed by the instantaneous hazard function $l(t)$. Other things equal, differences in mortality risks across occupations are the observable analogue of raising the mortality hazard by $dl > 0$ at each instant of a career from time 0 to the retirement date T. The value of a statistical life is the uniform increase in labor income dy that compensates for this increase in risk, resulting in $dV = 0$. Solving the displacement of (7), the value of a statistical life is

$$\text{(14)} \qquad \frac{dy}{dl} = -\frac{\int_0^\infty [y^F(t) + \Phi c^F(t)] S'_l(t)\,dt}{\int_0^T S(t)\,dt}$$

The empirical literature that studies tradeoffs between income and job-related mortality yields a "reasonable range" of values for dy/dl of $3 million to $7 million per statistical life (Viscusi, 1993). Suppose we settle on the midpoint of this interval, $5 million, as our value in (14) for a representative individual. Then knowledge of the time paths of (i) full income, (ii) full consumption, and (iii) mortality rates by age allow us to estimate Φ. Given this estimate, say $\hat{\Phi}$, we can return to (12) to estimate the change in the value of a life for factors that change the survivor function in any specific way. Focusing only on the value of changed mortality (that is, neglecting the value of changes in health) we obtain:

$$(15) \qquad V_q' = \int_0^{\infty} [y^F(t) + \hat{\Phi} c^F(t)] S_q'(t) dt$$

Equation (15) is the basis for our estimates of the value if increased longevity in the United States over the past several decades. The bracketed term is the value received at "age" t per unit change in the probability of survival to that age. It consists of "full income" plus a premium that is proportional to "full consumption" at that age.

Figure 1 illustrates the values of life by age for men and women based on a $5,000,000 value of a statistical life. For this calculation, the lifecycle profile of $y^F(t)$ plus the surplus on $c^F(t)$ is assumed to be proportional to a representative earnings profile for men from age 20 to 65. We use the value of the profile at age 20 for all years from birth to age 20. We also assume that the value of a life year declines at a rate of 5% per year after age 65. While somewhat ad hoc, this profile illustrates the main forces that determine the economic value of remaining life at different ages.

III. Estimating the Value of Actual and Potential Improvements in Health

The results in Section II have important implications for the valuation of both historical and prospective future improvements in life expectancy. To illustrate, we first apply the model to changes in mortality due to heart disease.

The effects of discounting are illustrated in Figures 2 and 3. Figure 2 shows the reduction in the death rate from heart disease by age category (measured by the change in annual deaths per 100,000 individuals in the population group). The reduction in death rates is concentrated at ages 55+ for men and 65+ for women. Figure 3 uses our framework to calculate the change in the value of life caused by these reductions in mortality. The value of the reduction in heart disease peaks for men at about age 50 (just prior to the major reductions is death rates for men) and for women at about age 65 (just prior to the major reduction in death rates for women). The peak at older ages for both sexes reflects the fact that heart disease deaths are concentrated at older ages. The difference in timing between men and women reflects the fact that deaths from heart disease typically occurred at somewhat younger ages for men than for women. The model attributes greater value to reductions in male heart disease because of the greater absolute reduction in death rates from heart disease among men, as shown in Figure 2.

Our model indicates that increases in life expectancy are worth more when survival rates are higher. This is in perhaps our most interesting result and has many implications. It accounts for the relatively low value placed on even large reductions in death rates at very old ages. At old ages the expected remaining length of life is so low that marginal increases in life have relatively low value. This can be seen by comparing Figures 2 and 3; the greatest reductions in death rates occurs in the two oldest age groups while the greatest increase in value of life occurs at significantly younger ages. This result also implies that improvements in life expectancy are complementary; progress against one disease raises life expectancy and therefore increases the value of further improvements in survival rates. For example, the reduction in death rates from heart disease shown in Figure 2 has served to increase the return to reducing death rates from cancer and other diseases prevalent late in life.

We generalize this analysis by addressing a broad question: What is the economic value of the increase in life expectancy that occurred between 1970 and 1990, *without regard to the sources of the increase*? To make these computations we use published data on death rates from all causes by age for 1970, 1980 and 1990 together with the reference profile for the economic value of life years by age shown in Figure 1. We first compare the value of life by age for the 1980 population, using 1980 survival rates, with what the value of life would have been for this population had survival rates remained at their 1970 values. This difference represents the value as of 1980 of the cumulative improvements in life expectancy that occurred between 1970 and 1980. The results are shown in Figure 4 and Table 1.

As Figure 4 illustrates, the gains at the individual level are substantial. Improvements in life expectancy had a peak value of about $170,000 for men between the ages of 40 to 55 and about $120,000 for women around age 40. The discretely larger increase in the value of life at age 0 for both sexes reflects the value of the reduction in infant mortality. The figure also shows the corresponding increases in values from 1980 to 1990. We do this in an analogous way by comparing the value of life by age for the 1990 population using 1990 survival rates, with what the value of life would have been for this population had survival rates remained at their 1980 values. While the gains from 1980 to 1990 are smaller than those from 1970 to 1980 they are still very large in absolute terms, on the order of $130,000 for 50 year old men and $60,000 for 50 year old women.

Table 1 aggregates the individual values in Figure 4 to determine the social value of the improvements in life expectancy that occurred between 1970 and 1990 (using equation (13)). The top half of Table 1 gives the distributions of the population across age groups and gender for 1980 and 1990 and the corresponding average increases in the value of life by age group and gender. We calculate the changes in value for three time periods, from 1970 to 1980, 1980 to 1990 and the average annual change from 1970 to 1990 (using the 1980 population distribution and survival benchmarks). The population data in the first two columns are the census population distributions for the indicated years. The rows labeled "Future" give estimates of the discounted present value (using a 3% interest rate) of the number of individuals in future cohorts (taken here to be a perpetuity at the current birth rate).

The lower panel of Table 1 accumulates the values across age and gender groups to provide estimates of the social value of these increases in life expectancy. These values are truly enormous: over $36 trillion for the change from 1970 to 1980 and $21 trillion from 1980 to 1990. The annual change, shown in the final column, amounts to about $2.8 trillion per year for the 1970 to 1990 period. This figure for the economic value of the annual improvement in life expectancy is more than half of real 1980 GDP ($4.6 trillion) and nearly equal to real aggregate consumption ($3.0 trillion) in that year. In other words, adding the increased value of life generated by advances in health to conventional measures of national output would increase real output over this period by a staggering 60%.

The improvements in health shown in Table 1 result from many sources in addition to improvements in medical knowledge. Examples are improvements in public health, changes in lifestyles (some of which may themselves be related to increases in medical knowledge), and increased access to health care. As such, they do not isolate the contribution of medical research and the knowledge gained from that research from the contribution of these other factors. They also do not deduct the economic cost of either the underlying medical research or the expansion of per-capita medical expenditures over this same period.

Tables 2 and 3 attempt to address these shortcomings. Table 2 calculates the economic value of the reduction in the risk of death from heart disease over the 1970 to 1980 and 1980 to 1990 time periods (both evaluated using the 1990 age distribution). Comparing Table 2 and Table 1 illustrates that a significant component of economic gains from the improvement in health from 1970 to 1990 are a result of the substantial reduction in deaths from heart disease that took place over this period. The reduction in heart disease death rates generates about half ($1.5 trillion) of the $2.8 trillion annual gain from the improvements in health.

It is also possible to deal explicitly with the increase in medical expenditures over time. Allowing for increases in expenditures seems important from both theoretical and empirical perspectives. In theory, identifying the marginal effect of knowledge requires us to control for changes in other inputs. This may be important since many technical advances also increase optimal expenditures. Empirically, we know that medical expenditures expanded enormously from 1970 to 1990. So it is necessary to control for expenditure growth whether these increases are causally related to the growth in knowledge or not.

If we allow expenditures to change with the level of knowledge then the marginal value of a change in knowledge will be

$$(16) \qquad \tilde{V}_\theta(a) = \int_{t=a}^{\infty} e^{-r(t-a)} \left(S_\theta(t,a) + S_Z(t,a)\, Z_\theta\right)(y^F + \Phi c^F) - S(t,a) Z_\theta \; dt.$$

Where Z_θ represents the increase in health expenditures in response to an increase in medical knowledge (i.e. $Z_\theta = dZ/d\theta$). The first term in brackets represents the total increase in the future value of life generated by both the increase in knowledge and the increase in expenditures. The second term represents the change in the discounted value of future health expenditures. Equation (16) implies that we can measure technical improvement (including the impact of changes in medical knowledge) as a sort of production residual equal to the increase in the discounted value of the increase in life years less the increase in expenditures. In fact, if health expenditures are chosen efficiently, then this expression will reduce to equation (12) since the net return to the marginal increase in Z will be zero. Indeed, equation (16) will measure the net contribution of health knowledge regardless of the source of the growth in health expenditures as long as health expenditures are chosen efficiently on the margin. We discuss the case where health expenditure choices are distorted below.

The improvements in health that we measured in Tables 1 and 2 include increases in life expectancy from all sources (including health expenditures). Then (16) implies that we can control for the effects of increased health expenditures by subtracting the growth in expected future expenditures from observed increase in the value of life. This will isolate the increase in the value of life due to sources other than the increase in expenditures. Table

3 does this by deducting the increase in discounted expenditures from the results in Table 2. As the table shows, the growth in remaining lifetime expenditures have been small relative to the increases in the value of life (on the order of 15%). Correcting for the increase in health expenditures reduces the growth in the value of life from $37 trillion to $34 trillion from 1970 to 1980, from $21 trillion to $16 trillion from 1980 to 1990, and the average annual increase from $2.8 trillion to $2.4 trillion. The results in Table 3 imply that there has been substantial improvement (indeed the vast majority of the total improvement) in life expectancy above and beyond what would be expected based on the growth in health expenditures alone. In economic terms, the health production sector has experienced rapid rates of technological improvement. Even so, it remains to be shown that this technical progress is due to medical research. Based on the extremely large numbers in Table 3, if even a small fraction of this improvement is due to medical research, the economic return to that research could be substantial.

The values in Table 3 may seem unbelievably large. Yet these estimates are a direct result of three basic factors: (1) the $5,000,000 value of life drawn from economic research on individuals' willingness to take on risk; (2) the magnitude of the reduction in death rates over the 1970-1990 period; and (3) the sheer size of the U.S. population, to which increases in the stock of knowledge can be applied. With these parameters, changes in health which increase life expectancy by 1 discounted life year generate an increase in the value of life of about $150,000 to $200,000 per person. With a population of 280 million this would imply a gain of about $42 to $56 trillion.

In order to evaluate the plausibility of generating such significant economic gains from progress against particular disease categories, Table 4 lists the gains to men, women and the population as a whole from eliminating deaths from various categories of disease. Figures 5 and 6 give the corresponding changes in the value of life at individual ages for men and for women. The numbers are computed using the 1995 distribution of individuals across age and gender groups and correspond to eliminating deaths from each specific disease holding age-specific death rates (not deaths) from other diseases constant. The $47 and $48 trillion dollar numbers for cancer and heart disease are staggering. These estimates imply that an innovation that reduced overall cancer death rates by only 1% would be worth almost $500 billion or about 6% of GDP. Reducing age-specific death rates from a single category of cancer such as breast or digestive cancer by 10% would have a similar value. Reducing the age-specific death rate from AIDS by 10% would be worth about $750 billion.

To put these values in perspective, we should note that total Federal support for health related research in 1995 was about $13 billion, or about 1/50 of the gain from a 1% reduction in the overall death rate from cancer. Even if we offset these gains by substantial increases in the cost of the treatments required to implement potential new technologies, the potential gains would still be very large – recall that the historical increase in expenditures was only about 1/8 of the total increase in the value of life and only 1/5 of the increase in the value of life from the reduction in heart disease alone. The results in Table 4 suggest that the potential economic gains to progress against the categories of disease listed in Table 4 are very large indeed.

IV. Investments in Medical Research

Our discussion so far has focused on the social value of past improvements in health and the potential gains to progress against various categories of disease. We now turn our discussion to funding for medical research. Table 5 provides some crude estimates of the investments in medical and aggregate R&D for the US in 1995 and the growth in R&D over the preceding decade. Our estimate of spending on medical research is based on data from the NIH Extramural Funding Data, fiscal year 1996 (Estimates of National Support for Health R&D). Values for total R&D and R&D for other sectors are based on the *Science and Engineering Indicators – 1998* published by the NSF. As Table 5 makes clear, the investment in medical R&D by the US is substantial, about $35.8 billion in 1995. Moreover, the level of funding for health research grew 80.1% in real terms between 1986 and 1995. In 1995 spending on health related research was equal to 3.5% of total health care spending, a percentage similar to the 2.5% of GDP accounted for by spending on aggregate R&D.

The growth in funding for medical research of 80.1% from 1986 to 1995 essentially kept pace with the 64.7% growth in health care spending over the same period and significantly outpaced the growth in overall GDP of 22.9%. The growth in medical research also outpaced the growth in overall R&D (80.1% versus 14.3%). The biggest contrast is for federally funded research, where federal funding for health related research increased by 45.8% in real terms while aggregate federal funding for R&D actually declined by 13.2%. It would appear, based on the numbers in Table 5, that health related research funding is about in line with funding in the economy as a whole on a percent of output basis and growth in this funding has roughly kept pace with the rapid growth in health care expenditures. Moreover, while the federal government's real dollar commitment to R&D in the economy as a whole has declined, its commitment to health related research has increased faster than GDP and almost as rapidly as health care expenditures.

Is the $35.8 spent on health related R&D in 1995 too high or too low from a social standpoint? While a precise answer to this question is beyond the scope of our analysis here, we can put some perspective on the issue. First, the amount spent on medical research is very small relative to the growth in the overall value of life figures shown in Tables 1-3. In fact, if we take the net annual number of $2.4 trillion per year for the 1970 to 1990 period (from Table 3) as a starting point, and assume that only 10% of this increase is due to increases in medical knowledge, then we are left with roughly a $240 billion annual gain. Compare this to the $36 billion annual expenditure on medical research for 1995. The estimates for the value of progress against specific disease categories from Table 4 tell a similar story. Reducing the death rate from heart disease or cancer by .1% (e.g. reducing the death rate per 100,000 from 100 to 99.9) would be worth about $50 billion or about 1.5 times our annual expenditures on health research.

The lower panel in Table 5 also provides some perspective on the current level of funding for health related research. The panel lists R&D expenditures as a percent of net sales for some of the most research-intensive industries. The 10.4% number for the drug industry is the highest of any industry. However, the 2.8% share for the health care sector as a whole ranks significantly behind the 8% shares for office and computing equipment, communications equipment, electronic components, and specialized instruments. The actual differences may in fact be somewhat larger since the R&D numbers for these industries are understated – the estimates include only industry-based research and do not include academic research in related underlying disciplines. In contrast, the 3.5% share for medical care is closer to the shares for motor vehicles and non-electrical machinery than it is to the R&D shares of high technology sectors. The identity of the sectors with the highest R&D

ratios provides no real surprises – the heavy R&D sectors are those closely linked to basic technologies: electronics, optics and biotechnology.

The R&D to sales figures in Table 5 suggest two types of comparisons. First we can compare the 3.5% figure for the health care sector as a whole to the figures for the other industries listed in the table and the 2.5% figure for the economy as a whole. As we noted above, the sectors with high R&D ratios are those where the links to underlying technological advances (in microelectronics, etc.) are highest. Should we expect the share of R&D for health care to be closer to those for high technology sectors or closer to shares of technologically mature sectors such as automobiles (3.0%) or the economy as a whole (2.5%). Our reaction is that medicine is an area closely tied to basic research, so its 3.5% R&D share appears surprisingly close to the 2.5% aggregate figure.

One of the potential reasons for the relatively low ratio of R&D to sales for health care (and the high dependence on government supported research) compared to high technology areas is that in a service based industry it may be difficult for private investors to capture the economic gains on the their investments. For service industries, technical advances may come in the form of procedures or techniques that cannot be patented or copyrighted, and so they do not lend themselves to providing returns to the original investor. The embodiment of ideas into physical goods creates an indirect way for innovators to collect on their investments in ideas. The view is bolstered by the difference between the 3.5% R&D to sales ratio for medical care as a whole and the 10.4% ratio for the drug sector. Since drugs are can be patented, they are not subject to many of the limitations characteristic of other advances in health knowledge. The reliance on federal funding also mirrors this idea: funding for drug related research is for all intents and purposes entirely industry based while funding for other areas of medical research is dominated by federal support. While not conclusive, the analysis of industry R&D to sales ratios suggests that spending on medical research is not high by economy-wide standards. In fact, it may be low relative to what is invested in other sectors with strong links to basic technological advances. It is indeed low relative to what is invested in the drug component of medical care sector itself.

The issue of the divergence between the social return to investments in medical knowledge and the incentives for private investors is endemic to discussions of R&D. As we have noted, this divergence is severe for innovations that cannot be embodied in physical goods that can be patented and sold. We believe that such distortions are important for understanding the current configuration of research funding and for guiding policy to funding medical research.

The medical sector is also subject to several other distortions that are important for our purposes. The first and most widely recognized factor is the prevalence of third party payers. Many medical spending decisions are made by individuals who bear only a small portion of the consequent economic costs. While the growth in managed care has altered this to some extent, it seems clear that third party payers will remain a key part of the medical care sector for the foreseeable future.

The key implication of this fact is that medical spending will tend to be higher than under a system where individuals bear the costs of their decisions. This has two implications. First, when we evaluate the gains to society from medical research, we must take account of the effect of increased knowledge on medical spending. Since individuals do not bear the costs of medical choices, it is possible that the induced increase in health expenditures could offset the direct gains from the medical knowledge. The most practical solution to this problem is to calculate the increased value of improved health net of the increase in medical spending (as we did in Table 3). This eliminates the need to separate the contributions to health of increases in medical knowledge and the associated increases in medical spending (which may be difficult both theoretically as well as empirically). Second, if increases in medical knowledge increase (or decrease) medical spending, any divergence between the cost and value of these expenditures will be accounted for in the calculations. Thus it would appear that while important, the impact of third party payers for evaluating the returns to medical research is something that can be dealt with.

The effect of third party payers also skews the pattern of research. Ideally, the search for medical advances would be driven by the potential net gains – the value of increased health and life expectancy less the true costs of the treatments and facilities needed to implement these advances. In the presence of third party payers, the weight placed on the economic costs of treatments will be reduced relative to the weight placed on the increased value of life. This will skew innovations toward towards those that are cost-increasing. This is aggravated by the fact that cost-increasing innovations often involve new equipment or drugs that allow at least limited ability to collect the value produced. Funding criteria for medical research should be conscious of these incentives, and perhaps lean toward development of cost-reducing innovations.

Another potential issue is the annuitization of benefits for older individuals. Private pensions, Social Security, private medical plans, and Medicare all provide annuitized benefits for retired workers. Under such systems, program benefits are income to older individuals (since they will not be received if the individual dies) and are valued as such. Yet from a social perspective they are really transfers, and should not be included in the valuation of life-extending innovations. As Becker and Mulligan (1997) have pointed out, this generates an excess incentive for individuals to invest in life-preserving activities. Empirically, this can be handled in our framework by reducing the estimated gains to life extension for each specific age by the value of annuitized payments received at that age. From a policy standpoint the prevalence of annuitized payments leads to over-investment in both treatments and research to increase life expectancy (but not quality of life).

Our analysis at this stage is too preliminary to support definitive conclusions. Yet it appears that current expenditures on medical research are extremely small relative to both the economic value of historical improvements in health and relative to the potential gains from even small progress against major categories of disease. Moreover, the level of R&D relative to sales for the health care sector is surprisingly close to the economy-wide average, and much smaller than for many of the “high technology” sectors. The R&D intensity for the medical sector as a whole is also small relative to the level of R&D intensity for the drug industry. This discrepancy may be related to the “basic” nature of much medical research and the inability for individuals to capture a substantial fraction of the social gains from medical research. We also find that there are several other distortions in the medical marketplace, in particular the prevalence of third party insurance and the annuitization of old-age benefits. Both factors distort incentives to expend resources on health care and so indirectly distort research incentives toward cost increasing life extension.

Our analysis suggests that even after taking account of these distorted incentives the potential gains to medical advancement are enormous. The remaining question is whether medical research is able to capitalize on this enormous potential for social gain. Based on our calculations, even limited progress would easily justify current expenditures and most likely expenditures above current levels. But even with expenditures fixed at current levels, our analysis provides a method for valuing the relative gains from progress on alternative research fronts, and helps to identify those areas where the current funding system is most likely to over or under invest.

V. Further Research

Our analysis so far has been very preliminary. While we have identified the enormous magnitude of the historical and potential future gains to increasing life extension, our analysis has also left much out. We have explicitly ignored the role of advances in medical knowledge for improving the quality (and not just the length) of life. We have made no attempt to isolate the impact on life expectancy of advances in medical knowledge specifically, or the output of the health care system as a whole, from the influence of other factors. We have made no attempt to directly link research and health outcomes. The data we have been using are largely preliminary and could almost certainly be improved in most dimensions by relying on more detailed, but publicly available, sources. Finally, the theoretical and analytical framework we have outlined here can be expanded along several dimensions including dealing with changes in health (as opposed to simply dealing with longevity) and allowing for lags in the impacts of medical knowledge and expenditures on health.

Refining the Value of Life Calculations – One area where we can improve the analysis here is in terms of the value of life calculations. Detailed empirical evidence on the lifecycle patterns of income and consumption can be used to obtain better estimates of the relative values of life at different stages of the lifecycle. In addition, a more thorough analysis of the literature on the valuation of life would help us validate or suggest modifications to some of the assumptions that underlie our empirical model.

Life Expectancy Data – Clearly, the life table data used in this paper play a central role in our analysis. Our estimates are pieced together from readily available sources and involved some significant interpolations where only data by age intervals or time intervals were easily available. It would be relatively straightforward to obtain more detailed data for each time period as well as extend the time period of our analysis to earlier years.

Disease Specific Data – One of the major improvements to our analysis would be to obtain more detailed data on the incidence of disease, death rates and life expectancy conditional on disease over time. Such data would allow us to better model the observed reduction in death rates and attribute these changes to reduced incidence and reduced death rates conditional on incidence at specific ages. Data on expenditures for the treatment of specific diseases over time would allow us to better model the relationship between expenditures, health improvement and the growth in medical knowledge. By looking at disease incidence we should also be able to gain some information about the correlations of disease risks. The disease specific model presented in this paper implicitly assumes that increased survival from one disease leaves the risks from other diseases unchanged. However, if the incidence of disease is correlated across diseases at the individual level this will not be the case. Given that many individuals often suffer from multiple conditions, this certainly is an issue that should be addressed.

Specific Data on Health Research – The data on health research presented in this paper is extremely crude. It covered only aggregate spending and even then was incomplete. In order to analyze the impact of research on health outcomes it is essential that we assemble the data on health research by disease category over time. Such data are available and have been analyzed for other purposes (see Lichtenberg 1998).

Data on Health and Quality of Life – Data on the quality of life by disease classification over time would allow us to extend our analysis beyond life expectancy and include direct health effects. Analysis of this type has been carried out by Cutler and Richardson (1997) in work similar in spirit to our work on the value of historical improvements in health. Their findings that improvements in health while alive account for about 30% of the increase in the value of life seems to suggest that incorporating health changes is potentially important. The framework they lay out for analyzing the value of changes in health (i.e. quality of life) would be an excellent starting point for such an analysis.

Linking Outcomes to Research – All of our proposed research projects so far have dealt with collecting additional or more detailed data. The improved data will allow us to refine the types of calculations carried out in our preliminary work. More detailed data by disease will also allow us to take the crucial second step and link the data on health outcomes to health research expenditures. Our basic plan of attack is as follows:

> The first step is to calculate the historical and potential gains to reductions in disease incidence, reductions in the death rates from disease conditional on incidence and increases in the quality of life conditional on disease.

> The second step is to calculate changes in health expenditures conditional on disease. This will allow us to calculate the net increase in the value of improved

health above and beyond the cost of increased expenditures. The bottom line of this second step will be the net increase in health care productivity by age, disease, and time period. This net difference represents the difference between the increase in the value of output and the growth in measured inputs and is analogous to the calculation of TFP growth in the standard analysis of industrial productivity.

The final step will be to link the productivity growth by disease and time period to expenditures on health research. This is the stage where the exact identification strategy is difficult to identify ex-ante and will depend on what data are available. The idea will be to look for exogenous variations in research expenditures that can be linked to variations in outcomes. The overall incidence of disease, the availability of specific funding and other factors may be candidate instruments. A final decision will have to wait until the data are assembled.

The Allocation of Research Dollars - While potentially useful for evaluating the overall impact of biomedical research, the analysis outlined above may be even more important for thinking about the allocation of research dollars. The empirical framework laid out above is ideal for evaluating the relative values of potential progress on alternative fronts. The theoretical model is also useful for identifying what areas and types of research are likely to be over or under funded based on individual incentives alone. More work on guiding the allocation of funds would seem to be a natural offshoot of this analysis.

Extending the Analytical Framework - As part of implementing the work outlined above we will need to extended the analytical framework outlined in this work to account for several factors including the cumulative nature of the effects of health knowledge and health expenditures on health and life expectancy. Essentially, this amounts to thinking of health as a stock variable that is accumulated by investments where the efficiency of these investments is determined by health care and other consumption expenditures and the level of health knowledge. This adds a dynamic element above and beyond that built into the model above. Exactly how much can be done on this margin from an empirical perspective remains to be seen but it seems like a direction of research worth pursuing. Dealing with a correlated structure of disease incidence will also require an expanded analytical framework. Finally, a more thorough theoretical and empirical analysis of the impact of third party payers, the annuitization of retirement benefits, and variation across treatments in the ability to collect returns on research breakthroughs are all potential policy offshoots of the analysis outlined above.

Clearly, much remains to be done.

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Table 1. The Economic Value of Increases in Life Expectancy from 1970 to 1980 and 1980 to 1990 by Age Group and Gender

Ages	Population Counts (1000's)		Increase in Value of Life($'s)		
	1980	1990	70 to 80	80 to 90	70 to 90 Annual
Males					
Future	55,747	63,993	$121,912	$60,128	$9,115
0 to 4	8,362	9,599	$89,076	$48,151	$6,873
5 to 13	15,923	16,295	$93,440	$51,120	$7,241
14 to 17	8,298	6,857	$107,818	$58,143	$8,313
18 to 24	15,054	13,738	$122,894	$61,362	$9,230
25 to 34	18,382	21,565	$150,683	$75,810	$11,347
35 to 44	12,570	18,511	$171,583	$110,890	$14,152
45 to 54	11,009	12,232	$167,068	$126,061	$14,687
55 to 64	10,152	9,955	$132,838	$102,660	$11,800
65 to 74	6,757	7,907	$78,376	$69,082	$7,388
75 to 84	2,867	3,745	$40,520	$36,076	$3,836
85+	682	841	$20,298	$18,604	$1,947
Females					
Future	53,240	61,053	$94,595	$41,532	$6,812
0 to 4	7,986	9,158	$67,776	$30,338	$4,911
5 to 13	15,237	15,532	$70,321	$30,821	$5,063
14 to 17	7,950	6,482	$81,969	$35,137	$5,862
18 to 24	14,969	13,212	$93,300	$38,268	$6,586
25 to 34	18,700	21,596	$110,115	$46,375	$7,833
35 to 44	13,065	18,924	$119,027	$56,165	$8,770
45 to 54	11,791	12,824	$114,295	$53,520	$8,401
55 to 64	11,551	11,158	$105,988	$45,143	$7,566
65 to 74	8,824	10,139	$90,422	$42,971	$6,677
75 to 84	4,862	6,267	$63,525	$33,547	$4,856
85+	1,559	2,180	$33,820	$18,701	$2,623

	Total Values (Millions of Dollars)		
	70 to 80	80 to 90	70 to 90 Annual
Males	**$20,547,654**	**$13,333,130**	**$1,619,017**
Females	**$16,042,877**	**$7,966,696**	**$1,158,343**
Total	**$36,590,530**	**$21,299,826**	**$2,777,360**

Table 2. The Economic Value of the Reduction in Heart Disease from 1970 to 1980 and 1980 to 1990 by Age Group and Gender

Ages	Increase in Value of Life($'s) 70 to 80	80 to 90
Males		
Future	$28,814	$27,874
0 to 4	$30,881	$29,873
5 to 13	$38,216	$36,969
14 to 17	$46,332	$44,820
18 to 24	$54,989	$53,195
25 to 34	$70,823	$69,280
35 to 44	$86,568	$89,228
45 to 54	$90,305	$96,547
55 to 64	$74,225	$83,247
65 to 74	$43,646	$57,699
75 to 84	$13,821	$29,746
85+	-$2,833	$12,012
Females		
Future	$15,042	$12,564
0 to 4	$16,093	$13,442
5 to 13	$19,898	$16,619
14 to 17	$24,091	$20,121
18 to 24	$28,457	$23,768
25 to 34	$36,109	$30,687
35 to 44	$44,998	$39,748
45 to 54	$52,191	$46,974
55 to 64	$54,220	$50,507
65 to 74	$43,599	$45,374
75 to 84	$20,576	$27,564
85+	$2,726	$10,342

	Total Values (Millions of Dollars) 70 to 80	80 to 90
Males	**$9,831,282**	**$10,107,711**
Females	**$5,729,049**	**$5,138,526**
Total	**$15,560,332**	**$15,246,237**

Table 3. The Net Economic Value of Increases in Life Expectancy from 1970 to 1980 and 1980 to 1990 by Age Group and Gender

Ages	Population Counts (1000's)		Increase in Value of Life($'s)		
	1980	1990	70 to 80	80 to 90	70 to 90 Annual
Males					
Future	55,747	63,993	$116,618	$50,418	$8,365
0 to 4	8,362	9,599	$83,619	$38,065	$6,096
5 to 13	15,923	16,295	$87,253	$39,680	$6,360
14 to 17	8,298	6,857	$100,813	$45,201	$7,316
18 to 24	15,054	13,738	$114,999	$46,812	$8,108
25 to 34	18,382	21,565	$141,816	$59,490	$10,088
35 to 44	12,570	18,511	$162,636	$94,271	$12,874
45 to 54	11,009	12,232	$158,782	$110,532	$13,496
55 to 64	10,152	9,955	$125,626	$89,084	$10,761
65 to 74	6,757	7,907	$72,795	$58,432	$6,576
75 to 84	2,867	3,745	$36,761	$28,883	$3,289
85+	682	841	$18,125	$14,405	$1,629
Females					
Future	53,240	61,053	$88,887	$31,132	$6,007
0 to 4	7,986	9,158	$61,873	$19,527	$4,075
5 to 13	15,237	15,532	$63,586	$18,490	$4,109
14 to 17	7,950	6,482	$74,305	$21,128	$4,778
18 to 24	14,969	13,212	$84,668	$22,512	$5,366
25 to 34	18,700	21,596	$100,397	$28,672	$6,462
35 to 44	13,065	18,924	$109,055	$38,038	$7,365
45 to 54	11,791	12,824	$104,755	$36,295	$7,062
55 to 64	11,551	11,158	$97,271	$29,594	$6,352
65 to 74	8,824	10,139	$83,215	$30,212	$5,678
75 to 84	4,862	6,267	$58,469	$24,658	$4,159
85+	1,559	2,180	$30,977	$13,773	$2,235

Total Values (Millions of Dollars)		
70 to 80	**80 to 90**	**70 to 90 Annual**
$19,441,601	**$11,040,528**	**$1,461,346**
$14,781,280	**$5,426,623**	**$980,800**
$34,222,882	**$16,467,151**	**$2,442,146**

Table 4. The Economic Value of Reducing Deaths from Selected Categories of Disease Overall and by Gender

	Increase in Value of Life($1,000,000's)		
Disease Category	**Men**	**Women**	**Total**
Cancer	**$24,325,209**	**$22,211,974**	**$46,537,183**
Breast	**$25,080**	**$4,617,170**	**$4,642,251**
Digestive Organs	**$5,469,042**	**$4,160,405**	**$9,629,447**
Genital and Urinary Or	**$1,810,372**	**$2,334,439**	**$4,144,811**
Heart	**$28,636,005**	**$19,711,577**	**$48,347,582**
Stroke	**$3,472,990**	**$4,156,135**	**$7,629,125**
Circulatory Disease	**$3,085,051**	**$2,654,387**	**$5,739,438**
Flu.	**$1,841,048**	**$1,591,013**	**$3,432,061**
AIDS	**$6,277,524**	**$1,262,572**	**$7,540,097**

Table 5. Expenditures on R & D - Bio-medical and Aggregate by Funding Source for 1995

Biomedical R&D Funding	**Expenditure ($1,000,000's)**	**% of Total**	**% Growth 1985-1995**	
Federal Government	$11,407	45.3%	53.8%	
Industry - Drug Industry	$10,202	40.5%	108.9%	*
Academic Research - Non Gov. Funding	$3,593	14.3%	******	
Total	$25,202	100.0%	75.7%	**
Spending on Health Care	$784,200		78.0%	
Health R & D as % of Health Expenditures	3.2%		-1.3%	
Health R & D as % of GDP	0.3%		38.6%	
Health R & D as % of Total R & D	13.8%		50.3%	**
Aggregate R & D Funding				
Federal	$63,147	34.5%	-12.1%	
Industry	$110,998	60.7%	220.1%	
Other	$8,868	4.8%	68.8%	
Total R & D Funding	$183,013	100.0%	16.9%	
GDP	$7,253,800		26.7%	
Total R & D as % of GDP	2.5%		-7.8%	
R & D as % of Sales (Selected Industries)				
Drugs & Medicines	10.4%			
Office & Computing Equipment	8.1%			
Communication Equipment	8.0%			
Electronic Components	8.0%			
Optical, Surgical & Photographic Equipment	8.0%			
Scientific Instruments	6.6%			
Industrial Chemicals	4.7%			
Motor Vehicles	3.0%			
Non-electrical Machinery	2.4%			

* Based on data for 1986

** Based on data for federal and drug industry only

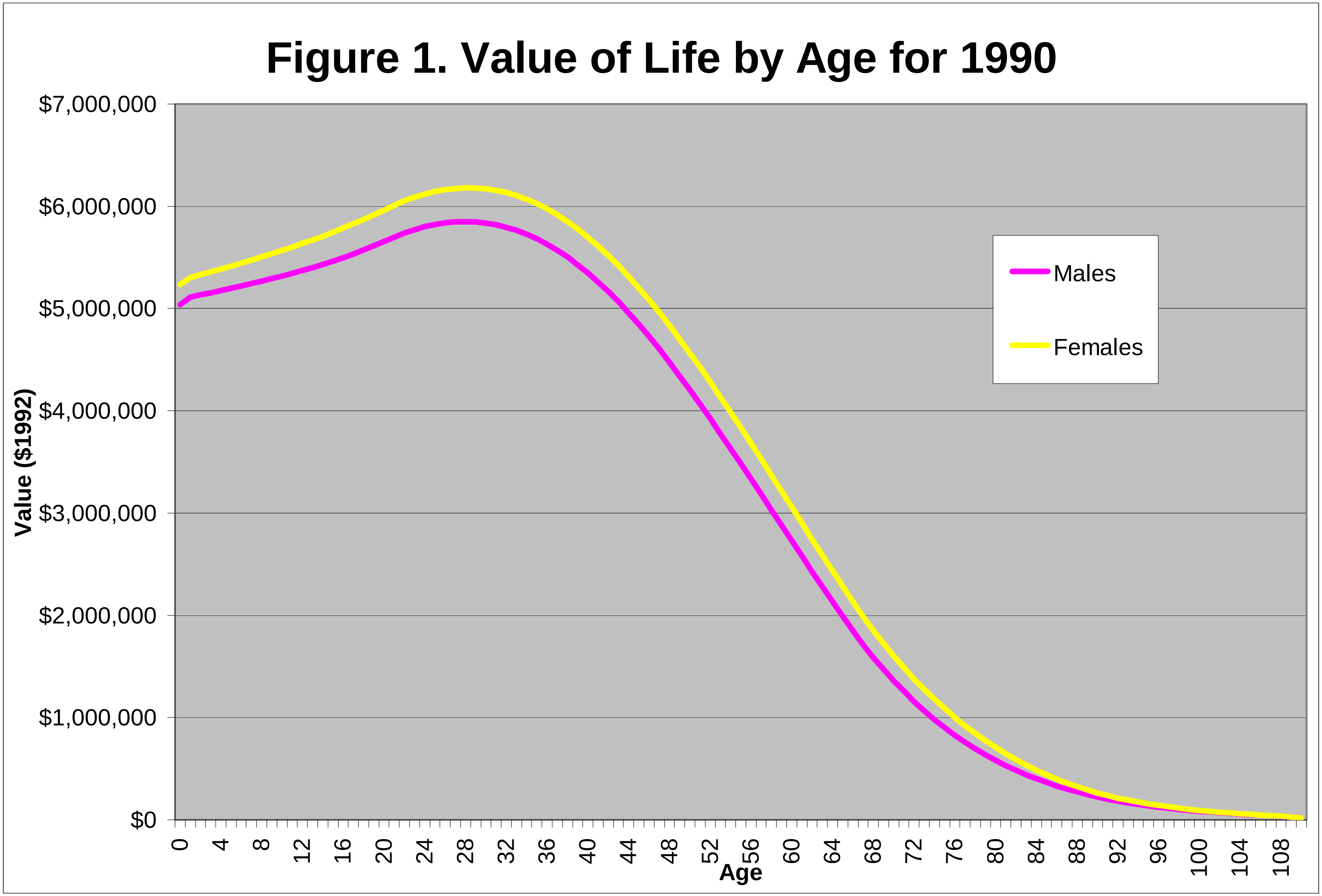
Figure 1. Value of Life by Age for 1990
Value ($1992)
$7,000,000
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
108
Age
Males
Females

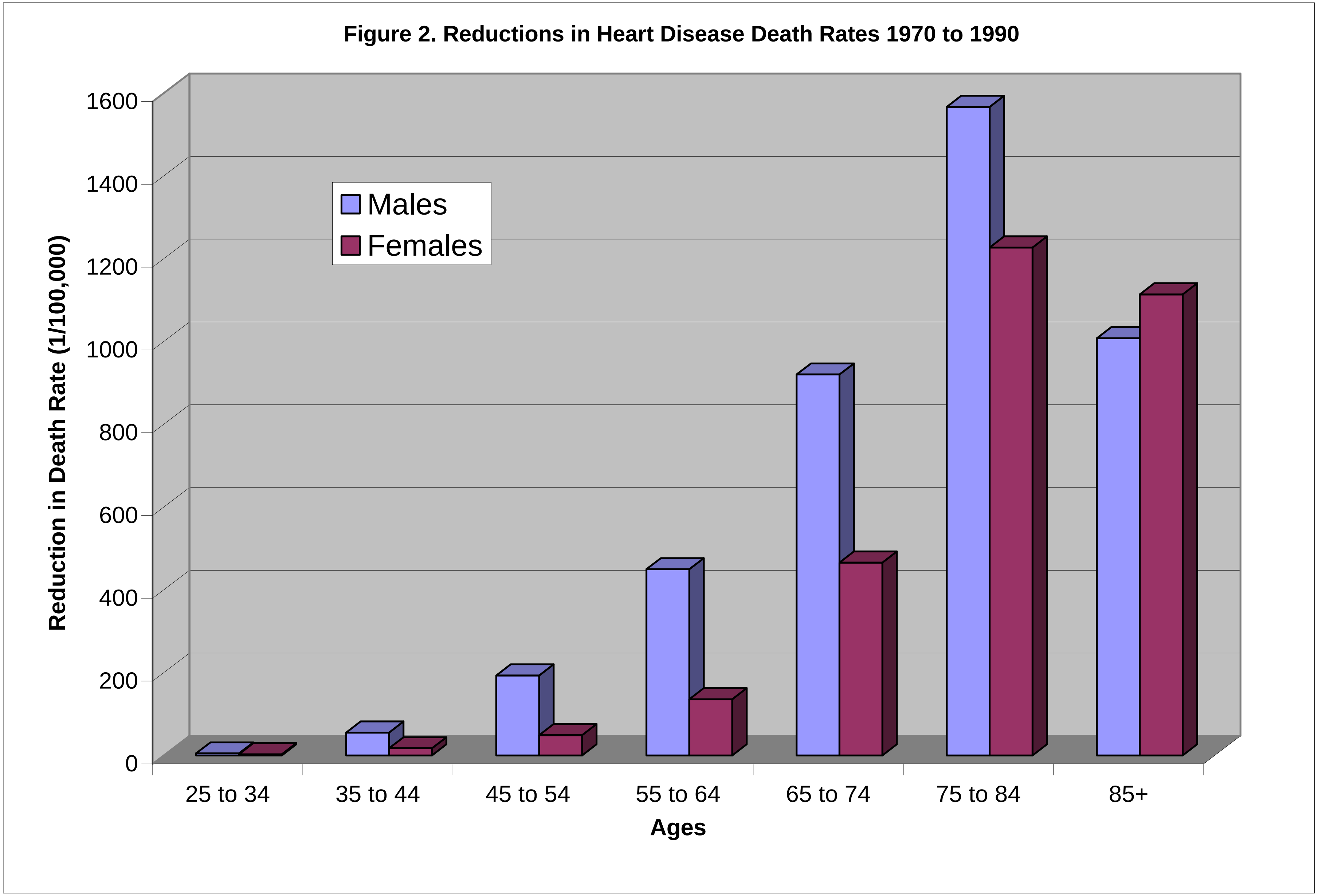
Figure 2. Reductions in Heart Disease Death Rates 1970 to 1990
Reduction in Death Rate (1/100,000)
1600
1400
1200
1000
800
600
400
200
0
Males
Females
25 to 34
35 to 44
45 to 54
55 to 64
65 to 74
75 to 84
85+
Ages

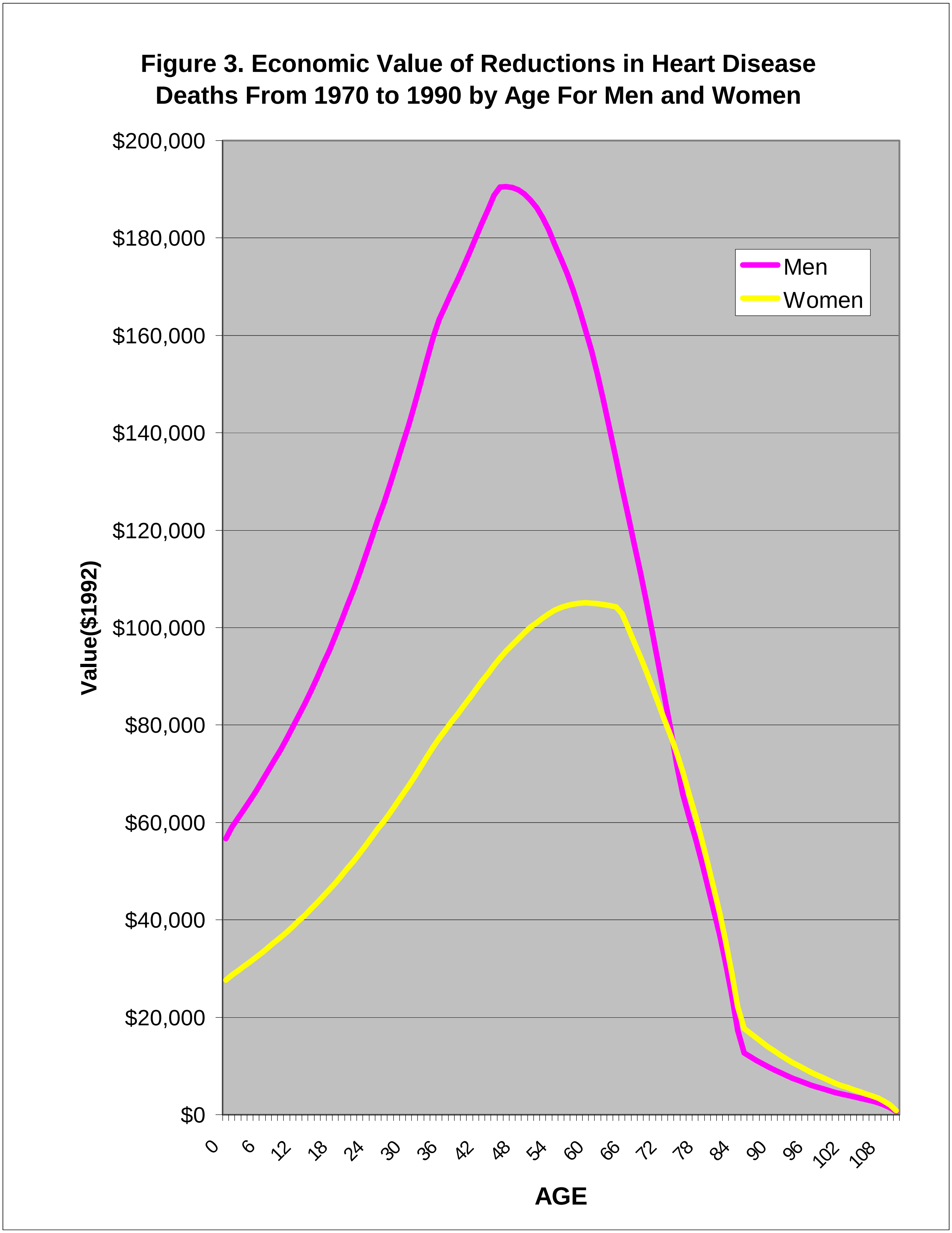
Figure 3. Economic Value of Reductions in Heart Disease Deaths From 1970 to 1990 by Age For Men and Women
$200,000
$180,000
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
Value($1992)
Men
Women
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
108
AGE

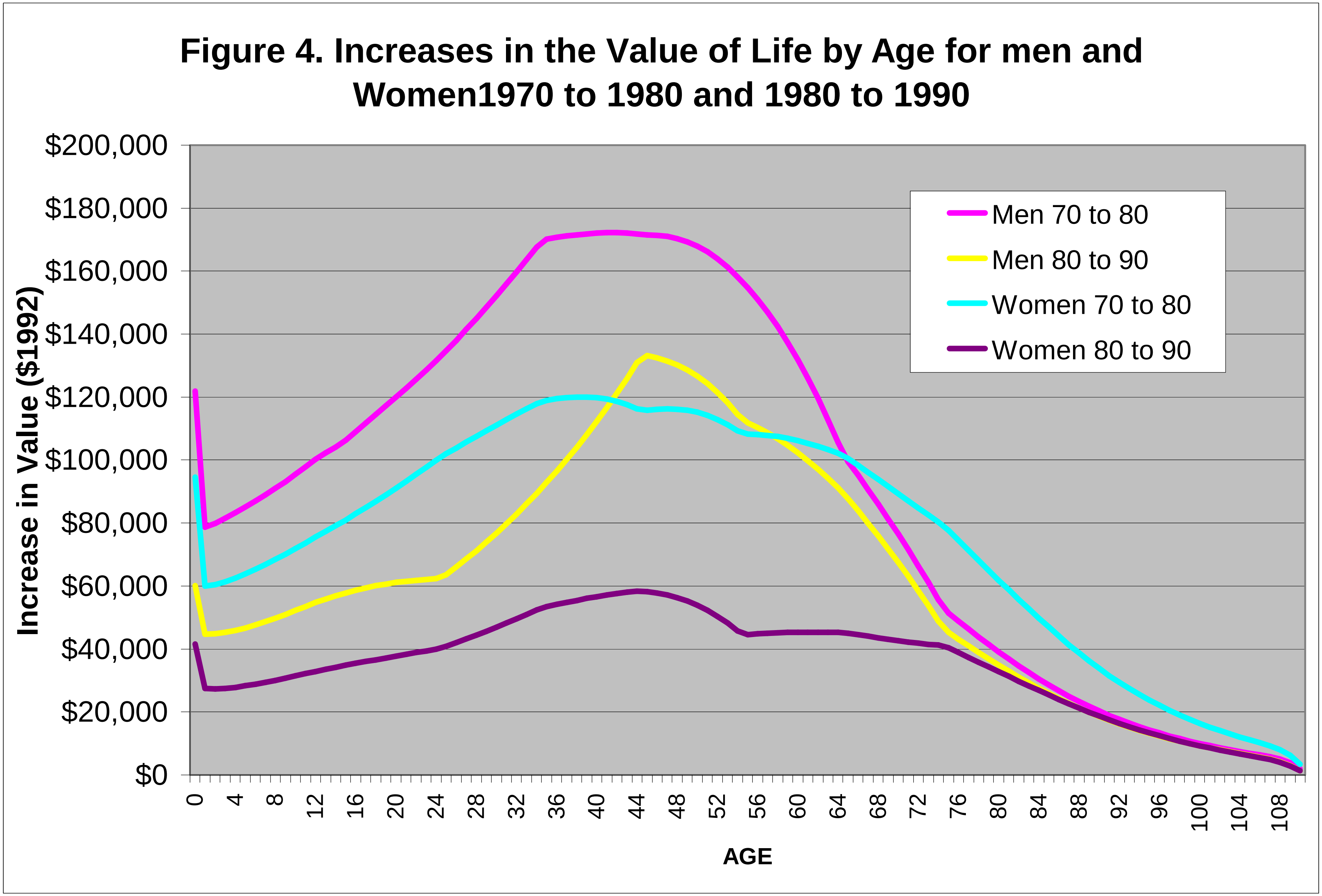
Figure 4. Increases in the Value of Life by Age for men and Women1970 to 1980 and 1980 to 1990
Increase in Value ($1992)
$200,000
$180,000
$160,000
$140,000
$120,000
$100,000
$80,000
$60,000
$40,000
$20,000
$0
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
108
AGE
Men 70 to 80
Men 80 to 90
Women 70 to 80
Women 80 to 90

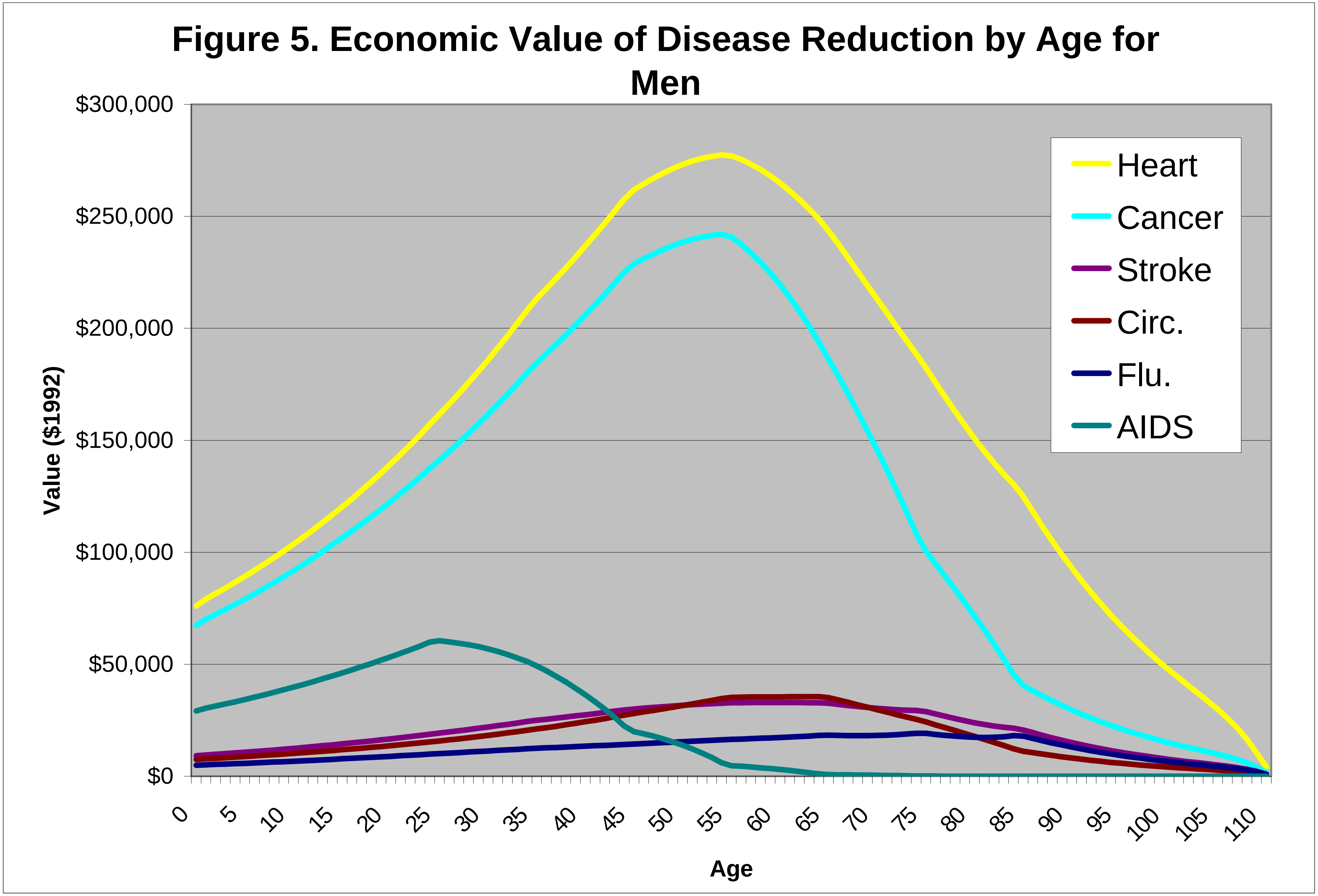
Figure 5. Economic Value of Disease Reduction by Age for Men
Value ($1992)
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
Age
Heart
Cancer
Stroke
Circ.
Flu.
AIDS

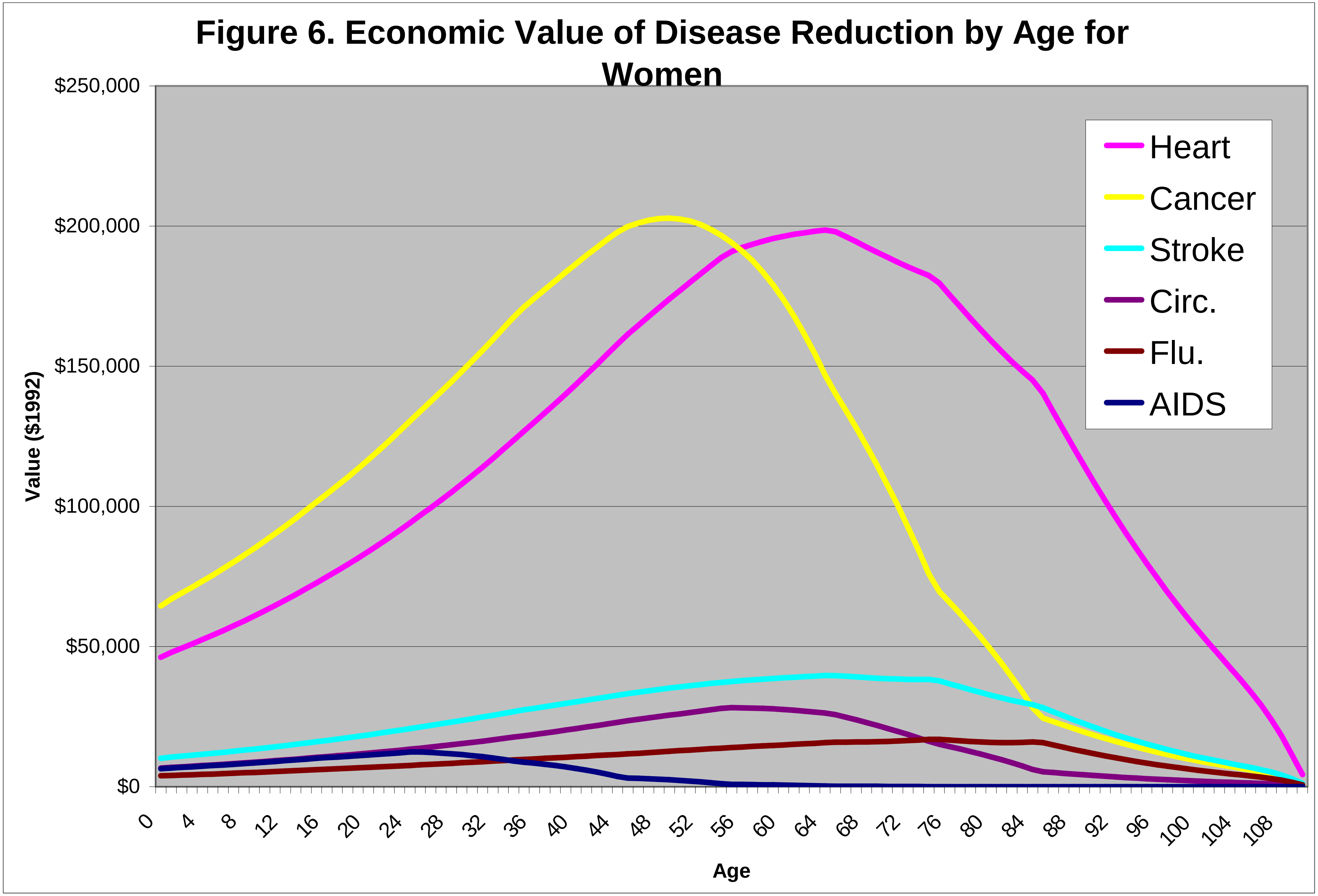
Figure 6. Economic Value of Disease Reduction by Age for Women
$250,000
$200,000
$150,000
$100,000
$50,000
$0
Value ($1992)
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
108
Age
Heart
Cancer
Stroke
Circ.
Flu.
AIDS