NBER WORKING PAPER SERIES

ACCOUNTING FOR FUTURE COSTS IN MEDICAL COST-EFFECTIVENESS ANALYSIS

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Working Paper 5946

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 1997

This work was supported by a fellowship in the Economics of Aging and Health Care supported by the National Institute on Aging and National Bureau of Economic Research (Grant #T32-AG00186) while I was completing my residency at Brigham and Women's Hospital. I am grateful to the NIA, NBER and Brigham and Women's Hospital for their support. I am also grateful to Douglas Staiger, Joseph Newhouse, and an anonymous referee for useful comments on earlier versions of this paper. This paper is part of NBER's research programs in Health Care and Productivity. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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JEL Nos. I18, D61
Health Care and Productivity

ABSTRACT

Most medical cost-effectiveness analyses include future costs only for related illnesses but this approach is controversial. This paper demonstrates that cost-effectiveness analysis is consistent with lifetime utility maximization only if it includes all future medical and non-medical expenditures. Estimates of the magnitude of these future costs suggest that they may substantially alter both the absolute and relative cost-effectiveness of medical interventions, particularly when an intervention increases length of life more than quality of life. In older populations, current methods overstate the cost-effectiveness of interventions which extend life compared to interventions which improve the quality of life.

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Introduction

Medical cost-effectiveness analysis is intended to provide a guide for choosing among potential medical interventions in order to achieve the best possible outcomes given the available resources. For any level of expenditure, the greatest benefit can presumably be achieved by adopting those interventions which offer the greatest benefit per unit of cost and abandoning those interventions which offer the least. Despite significant questions concerning the validity of existing approaches to cost-effectiveness analysis, the imperative to control health care costs in the face of the continuing development of new technologies has increased the prominence of cost-effectiveness analysis in major medical journals and in the research agendas of health care organizations, including government, pharmaceutical firms and health maintenance organizations.

The majority of methodological research in medical cost-effectiveness analysis to date has focused on refining measures of the benefit of medical interventions. For example, the recognition that effects on disease-specific mortality may be of little value if people progress rapidly to die of either related or unrelated causes has led researchers to attempt to demonstrate effects on total mortality or life expectancy. Likewise, the awareness that extensions of life may be less valued if they are associated with substantial morbidity has caused researchers to investigate the effects of medical interventions on the overall quality of life, as often measured by quality adjusted life expectancy (QALE). A variety of approaches have been used to assess quality of life, including rating scales, standard gamble, time trade-off, person trade-off and ratio scales (Torrence, 1986; Nord 1992). Not surprisingly, the validity of these cardinal measures of the quality of life and their use in the assessment of QALE have been controversial (Loomes et el.(1989), Torrance et al. (1989), LaPuma and Lawlor (1990)).

Meanwhile, far less attention has been paid to how to measure costs. In some instances, the set of costs accounted for is determined by the specific objectives of the decision maker. For example, in evaluating a new screening technology, Medicare may only consider costs to the Medicare program while an HMO may only consider costs incurred while an individual remains covered by the HMO. More typically, researchers concerned with the formulation of public policy attempt to identify the total costs and benefits of the intervention to society.

The question of how to handle future medical costs which occur when a medical intervention extends life has arisen frequently, but remained unresolved. Most studies include future medical costs for related illnesses but ignore changes in medical expenditures for "unrelated" illnesses which result from changes in survival due to medical interventions. In a paper comparing the cost-effectiveness of screening for breast cancer with that of other health care interventions, Mushlin and Fintor (1992) write:

> It is generally accepted that the additional costs directly attributable to breast cancer should be included in cost-effectiveness analyses of the disease specific intervention. Any additional costs for the treatment of unrelated diseases because individuals live longer due to screening and early treatment of breast cancer are excluded from the analysis... None of the studies evaluated include these unrelated costs. As such, they all avoided the nonsensical conclusion that it is almost always more cost-effective to do nothing than to screen and attempt cure.

In "Is Prevention Better than Cure?" (1986), Louise Russell also supports these basic ideas and extends them to argue for the exclusion of future non-medical expenditures:

> ... if the purpose of the analysis is instead to determine whether the program is a good investment, only the costs of the preventive program should be counted. Added years of life involve added expenditures for food, clothes, and housing as well as medical care. None of these is relevant to deciding whether the program is a good investment.

Thus the most common current practice in cost-effectiveness analysis is to include medical costs for "related" illnesses while excluding costs for "unrelated" illnesses and future non-medical expenditures. While there does seem to be some intuitive distinction between "related" and "unrelated" costs, it is worth noting that what constitutes a "related" cost is not always clear. In the Mushlin and Fintor example, related costs are the costs due to the treatment of the single disease in question (breast cancer), while in other studies such as the Coronary Heart Disease Policy Model (Weinstein 1987), the scope is widened to account for other diseases such as stroke which are linked through shared physiologic mechanisms. This suggests that there is an inherent arbitrariness to which costs are considered "related" and "unrelated".

In their textbook on decision analysis, Weinstein, Feinberg, et al. (1980) suggest a very different approach to the measurement of future medical costs:

> ... if treatment results in prolonged life because a condition has been cured or early disease has been avoided, then the cost of treating later disease that would not

otherwise have arisen must be considered. For example, a patient who survives a heart attack may subsequently develop cancer. This is not to say that the net effect is negative but simply that the cost of treating cancer must be counted as a cost, while the benefit of prolonged life is counted on the health side.

Thus Weinstein et al. suggest that all future medical costs should be included. On the other hand, even Weinstein does not go so far as to support the idea that cost-effectiveness analyses include non-medical expenditures. In his presidential Address to the Society for Medical Decision Making, he writes:

> The opposing view holds that if health care costs are to be counted in this way, so should all other costs of subsistence during the added years of life. I do not follow this argument, since the explicitly constrained resource is health care cost, and other costs are the price we all willingly pay to live.

Thus Weinstein takes the view that medical cost-effectiveness analysis should be viewed as a tool for allocating a health care budget, and should not be concerned with non-medical expenditures.

One reason for the persistent differences in opinion about how to treat future costs is that there has been no solid theoretical basis for these arguments. Given this void in the literature, Garber and Phelps (1992) make a major contribution by proposing that cost-effectiveness methodology be evaluated by its consistency with expected utility theory. Surprisingly, they conclude that it does not matter whether future costs are included because the relative rankings of procedures will be preserved in either case, as long as future costs are treated consistently. The result is an important one because it suggests that existing studies which generally do not account for future costs of medical care can reliably be used for ranking the cost-effectiveness of interventions.

Despite the attractiveness of this theoretical result, the formulation of lifetime resource allocation used by Garber and Phelps contains strong restrictions on the substitution of income across time and potential outcomes. This paper uses a more general formulation of lifetime expected utility maximization to reexamine the appropriate treatment of future medical costs. When these restrictions are relaxed, cost-effectiveness criteria are found to be consistent with utility maximization only if they include all future expenditures, whether medical or non-medical. As a result, other methods of measuring costs will not generally yield optimal rankings of procedures and existing studies of cost-effectiveness may not provide a reliable guide to resource allocation. Estimates of the magnitude of these future unrelated costs suggest that they may substantially alter both the absolute and relative cost-effectiveness of many medical interventions, particularly when an intervention increases the length of life more than the quality of life. In older populations, existing approaches to cost-effectiveness analysis are biased to favor interventions which extend the length of life over interventions which improve the quality of life. In younger populations, the opposite may hold.

These findings suggest that effects on future medical and non-medical expenditures should be routinely considered in cost-effectiveness analyses. In addition, they provide a framework for understanding the potential difficulties with the application of cost-effectiveness analysis to elderly populations, call into question traditional paradigms for budgeting health care resources and raise important issues concerning the ethical basis of cost-effectiveness analysis.

Section I describes the theoretical model and generalizes the results to account for the value of time spent in non-market activities. The valuation of non-market time is important to address the concern that including earnings and resource utilization in cost-effectiveness analysis would inappropriately bias the analysis against the elderly, and others who tend to be outside the labor force. Section II examines the quantitative significance of these results for the absolute and relative cost-effectiveness of medical interventions. The results suggest that future unrelated costs may substantially alter both the total cost and relative cost-effectiveness of many interventions, particularly when an intervention increases length of life more than quality of life. Section III concludes and discusses directions for future investigation.

Section I: Theoretical Model

Expected Utility

Expected utility provides a convenient framework for analyzing the effects of changing medical expenditures on lifetime utility. Following this approach, lifetime utility is equal to the sum over all ages of the utility at each age (U_t) weighted by the probability of surviving to that age (S_t) and a time preference discount factor β^t (where $\beta<1$):

$$EU = \sum_{t=1}^{T} \beta^t S_t U_t .$$

In general, medical interventions affect lifetime utility through their effects on survival probabilities and their effects on utility in each period by improving health. Because the vast majority of medical interventions result in physiologic changes which may persist far into the future (i.e. immunization, coronary artery bypass, control of hypertension or hypercholesterolemia), it is important that the theoretical framework for examining cost-effectiveness analysis account for these effects. Accordingly, the probability of survival to time t is assumed to depend on the whole history of k = 1,...K possible medical interventions in each period up to that point. Thus $S_t = S_t(m_{11},..m_{Kt-1})$ where m_{kt} is expenditure on medical intervention k at time t. Other formulations of the effect of medical intervention on health such as that of Grossman (1972) and Garber and Phelps (1993) are special cases of this. In Grossman's formulation, past expenditures on health can alter the underlying health (H_t) of an individual and therefore the effect of current medical expenditure on the probability of survival so that $S_t(m_{11},..m_{Kt-1}) = S_t(H_{t-1}(m_{11},...m_{Kt-2}),m_{1t-1},...m_{Kt-1})$. Garber and Phelps present their full analysis with a flexible formulation similar to the general one used here[1].

Since health outcomes are far from fully predictable, it is important to consider both the random component of health and the possibility that individuals may wish to purchase insurance against the

[1] Garber and Phelps also present a simpler model in which the probability of surviving a period conditional on reaching that period is independent of previous medical expenditures. Thus the probability of surviving period t conditional on reaching it, $S_{t+1}(m_{11},...m_{Kt}) / S_t(m_{11},...m_{Kt-1})$, depends only on current health expenditures $\{m_{1t},...m_{Kt}\}$. Since most medical interventions are likely to have effects which stretch into the future, this is a strong assumption which limits the value of that model for understanding how to treat future costs in medical cost-effectiveness analysis.

financial components of these risks. To address these issues, health expenditures can be viewed as Arrow-Debreu type contingent commodities which depend on the whole history of previous health shocks (i.e. $m_{kt}(\varepsilon_1,...\varepsilon_{t-1})$) while the probability of survival depends on both the history of health shocks and the history of medical expenditures so that $S_t = S_t(m_{11},..m_{Kt-1},\varepsilon_1,...\varepsilon_{t-1})$. In a sufficiently large population, the fraction of a population surviving to time t will approach the population mean value, $S_t(m_{11},..m_{Kt-1})$. Because the Arrow-Debreu formulation significantly complicates the presentation of the results without changing their substance, the full Arrow-Debreu formulation of the problem and a discussion of the existence and optimality of a competitive equilibrium are presented in Appendix 1, while the main text describes the behavior of the model in a large population where the aggregate outcomes approach certainty in the limit.

Quality adjusted life expectancy (QALE) incorporates the idea that diminishing levels of health may compromise the value of life extension. This can be represented formally by allowing the level of utility to depend on the level of health so that $U_t = U_t(H_t(m_{11},..m_{Kt-1}))$. The most common version of this formulation models utility in a period as a disease state-specific constant, U_j, which reflects the average utility of an individual with a specific disease state j. Studies that use life expectancy as an outcome measure can be considered a special case of this in which utility in each period is fixed at 1.

One limitation of QALY models is that they do not reflect the idea that differences in individuals' levels of consumption can also influence their utility. The dependence of utility on consumption is important in order to explain why people do not spend their entire income on health care. To incorporate this, utility is assumed to also depend on consumption so that $U_t = U_t(c_t,H_t(m_{11},..m_{Kt-1}))$ where c_t is consumption in period t. Expenditures on medical care are considered not to provide direct utility and therefore do not enter into the utility function directly.

Combining these baseline assumptions, expected lifetime utility can be written as:

$$(1) \qquad EU = \sum_{t=1}^{T} \beta^t \, S_t(m_{11},...m_{Kt-1}) \; U_t(c_t,H_t(m_{11},..m_{Kt-1})).$$

Resource Constraints

In aggregate across individuals, the sum of expenditures on consumption and medical care cannot exceed the sum of earnings plus any endowments of resources. For a given individual, the actual realizations of these values will vary depending on their health and mortality experience. However, as the number of individuals in a society becomes large, the aggregate variation in expenditures and resources will decline and formal and informal insurance can arise to permit individuals to be constrained only that their expected level of expenditures equal their expected resources. This spares each individual the need to save resources equal to the money he would require were he to reach an extremely old age and therefore avoids the need to tolerate lower than desired spending in the present and the potential for undesired reserves at the end of life. The constraint that an individual's expected level of expenditures equal his expected resources is represented formally by:

$$(2)\quad \sum_{t=1}^{T} \left[\frac{1}{1+r}\right]^{t} S_t(m_{11},...m_{Kt-1})\,(c_t + \sum_{k=1}^{K} m_{kt}) = \sum_{t=1}^{T} \left[\frac{1}{1+r}\right]^{t} S_t(m_{11},...m_{Kt-1})\, i_t$$

where r is the interest rate earned by resources which are saved during a period rather than consumed and i_t is the income earned in each period.

Optimal Expenditures on Medical Care

Having defined the expected utility function (1) and the resource constraint (2), it is now possible to identify the optimal expenditures on medical care (and consumption) over time by choosing c_t and m_{it} to maximize equation (1) subject to equation (2). This yields first order conditions:

$$(3)\quad \beta^t S_t(m_{11},..m_{Kt-1}) \frac{\partial U_t(c_t,H_t(m_{11},..m_{Kt-1}))}{\partial c_t} = \lambda \left\{ \left[\frac{1}{1+r}\right]^{t} S_t(m_{11},..m_{Kt-1}) \right\} \qquad t = 1...T$$

$$(4)\quad \sum_{\tau=t}^{T} \beta^{\tau} \left[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}} U_\tau(c_\tau,H_\tau(m_{11},..m_{K\tau-1})) + S_\tau(m_{11}..m_{K\tau-1}) \frac{\partial U_\tau(c_\tau,H_\tau(m_{11},..m_{K\tau-1}))}{\partial m_{it}} \right]$$

$$= \lambda \left\{ \left[\frac{1}{1+r}\right]^{t} S_t(m_{11}..m_{K\tau-1}) + \sum_{\tau=t}^{T} \left[\frac{1}{1+r}\right]^{\tau} \left[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}} [c_\tau + \sum_{j=1}^{K} m_{j\tau} - i_\tau] \right] \right. \qquad i = 1...K,\ t = 1...T$$

Equation (3) ensures that the discounted expected marginal utility of consumption at each age equals the discounted expected cost. Equation (4) ensures that the expected utility gained through a medical expenditure equals the expected costs related to that intervention. Medical interventions affect expected utility both by changing survival probabilities and by changing health during life. Similarly, costs have two components. The first is the direct cost of the intervention, as represented by the first term on the right side of (4). The second is the effect on net expenditures generated by the change in survival probabilities because the length of life is changed. This is the discounted value of the additional expenditures on consumption and medical care net of any earnings, as represented by the second term on the right side of (4).

Implications for Cost-Effectiveness Analysis

Cost-effectiveness analysis is based on the principle that the greatest amount of benefit can be derived from a given level of expenditure by allocating expenditures to those activities which generate the greatest benefit per unit of expenditure. A related measure can be derived by rearranging the above conditions for utility maximization to yield the following condition for the optimal allocation of medical expenditures:

$$(5)\quad \frac{[\frac{1}{1+r}]^{t} S_t(m_{11}..m_{K\tau-1}) + \sum_{\tau=t}^{T}[\frac{1}{1+r}]^{\tau}[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}}[c_\tau+\sum_{j=1}^{K} m_{j\tau}-i_\tau]]}{\sum_{\tau=t}^{T}\beta^{\tau}[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}} U_\tau(c_\tau,H_\tau(m_{11}..m_{K\tau-1})) + S_\tau(m_{11}..m_{K\tau-1})\frac{\partial U_\tau(c_\tau,H_\tau(m_{11}..m_{K\tau-1}))}{\partial m_{it}}]} = \frac{1}{\lambda}$$

$$i = 1...K, t = 1...T$$

The numerator of the ratio on the left side of this equation is the total discounted increase in costs resulting from the increase in medical expenditure. The denominator is the additional discounted utility generated by the medical expenditure. Equation (5) shows that an optimal allocation of resources requires that the ratio of the marginal cost to the marginal benefit of all interventions be set equal to the same value, $1/\lambda$. Equation (3) provides an interpretation of the meaning of λ, namely that it is the marginal utility of income. In principle, equations such as (5) could provide a theoretical basis for cost-effectiveness analysis. If changes in utility and costs could be appropriately measured, one would select those interventions for which the cost-effectiveness ratio is highest (and, in fact, expand their use to the point where the cost-effectiveness ratio for all possible uses of resources was equal - and equal to $1/\lambda$).

Equation (5) answers the question concerning future medical costs. In contrast to current practice, equation (5) implies that cost-effectiveness analysis must include the total change in future expenditures which results from a medical intervention, regardless of whether those expenditures are medical or non-medical. Likewise, there is no basic distinction between "related" and "unrelated" medical expenditures in this equation. It does seem rather counterintuitive that a hamburger eaten or cholesterol level checked 20 years after someone's life is saved by a given medical intervention should be counted as a cost of that intervention, but that is the implication. The intuition behind the result is that the benefits of extending life include the utility generated by those future expenditures and the analysis therefore must also include the costs necessary to obtain that utility. If the intervention had never taken place, those resources would have been available for other uses.

The two terms in the numerator in Equation (5) refer to current and future costs, so that the cost-effectiveness ratio can be viewed as being the sum of a component related to current cost and a component related to future cost. The omission of future "unrelated" costs from current cost-effectiveness analyses thus constitutes a bias in current measures of cost-effectiveness. The existence of this bias implies that rankings of interventions based on cost-effectiveness criteria which neglect future costs will not generally lead to a ranking of medical interventions consistent with utility maximization.[2] Equation (5) also provides several insights into the nature and magnitude of that bias. The most important is that the bias due to the omission of future costs is related to changes in survival, as reflected in the second term in the numerator. This implies that the bias is zero when there are no effects on survival. Therefore, current procedures which neglect future costs are fully measuring the costs of interventions which improve only the quality of life, while not fully accounting for the costs of interventions which extend the length of life. Thus, as long as net future costs are positive, current approaches are biased to favor interventions which extend life over those which improve the quality of

[2] Of course, comparisons of cost-effectiveness ratios which include future costs to those which do not will also not generally lead to a ranking of medical interventions consistent with utility maximization.

life. The fact that interventions which extend life may also have effects on its quality is reflected in the second term in the denominator, and implies that this bias need not be proportional to changes in survival. In fact, in cases in which an intervention decreases the average quality of life, the bias in the cost-effectiveness ratio expressed in a metric such as cost per quality adjusted life year can far exceed the annual future costs themselves. The empirical implications of this are explored in Section II.

The finding that non-medical expenditures should be included in the determination of cost-effectiveness also has important implications for the concept of a health care budget, as described in the quote cited above from Weinstein (1986). That approach assumes it is possible to achieve an efficient allocation of health care resources by taking a given budget for health care resources and then allocating it to maximize quality-of-life-adjusted health outcomes. The broader definition of cost-effectiveness suggested here implies that this would not yield the appropriate allocation of resources since changes in earnings and consumption resulting from changes in survival due to medical interventions would not be appropriately taken into account. This would tend to artificially encourage interventions which extend life in the elderly relative to those which improve their quality of life or extend life in younger individuals. These neglected costs could be considered a "hidden" or "off-budget" cost of health care. Thinking about health care spending in terms of a "health care budget" thus overstates the attractiveness of interventions which extend life compared to interventions which improve the quality of life or enhance productivity.

Marginal vs. Total Costs and Effectiveness

Because it describes a ratio of marginal cost and marginal utility, equation (5) theoretically eliminates the need to consider changes in costs and utility which arise because a medical intervention changes the optimal degree of spending on other interventions. In practice, however, it may be difficult to assess the pure marginal effect of an intervention, since differences in utility between individuals with and without the intervention would also reflect changes in related interventions. For example, a comparison of the quality of life of individuals with angina treated with bypass as opposed to angioplasty would not only reflect any differences in quality of life due to the revascularization procedure itself, but also any differences in quality of life which result from changes in medical management made possible by the revascularization procedure.

To generalize the concept of cost-effectiveness to address this concern, it is useful to consider the total effects of a medical expenditure on utility and costs when other interventions are allowed to adjust optimally. To simplify notation, equations (3) and (4) can be written as:

$$\frac{\partial EU}{\partial c_t} = \lambda \frac{\partial E}{\partial c_t} \text{ for all } t, \tag{6}$$

$$\frac{\partial EU}{\partial m_{kt}} = \lambda \frac{\partial E}{\partial m_{kt}} \text{ for all } k \text{ and } t, \tag{7}$$

where EU is expected utility and E is expected expenditures. The ratio of total change in costs and utility is then described by:

$$CE = \frac{\dfrac{dE}{dm_{it}}}{\dfrac{dEU}{dm_{it}}} = \frac{\dfrac{\partial E}{\partial m_{it}} + \sum\sum_{j\tau \neq it} \dfrac{\partial E}{\partial m_{j\tau}} \dfrac{dm_{j\tau}}{dm_{it}} + \sum_{t=1}^{T} \dfrac{\partial E}{\partial c_\tau} \dfrac{dc_\tau}{dm_{it}}}{\dfrac{\partial EU}{\partial m_{it}} + \sum\sum_{j\tau \neq it} \dfrac{\partial EU}{\partial m_{j\tau}} \dfrac{dm_{j\tau}}{dm_{it}} + \sum_{t=1}^{T} \dfrac{\partial EU}{\partial c_\tau} \dfrac{dc_\tau}{dm_{it}}} \tag{8}$$

where $\frac{dm_{j\tau}}{dm_{it}}$ and $\frac{dc_\tau}{dm_{it}}$ describe the changes in the optimal levels of other medical inputs and consumption which occur when the health input under investigation is altered. Thus, in addition to the immediate expenditure on an intervention, the total costs of the intervention will include expenditures which occur because an intervention increases the probability of survival to a given period and expenditures which occur because an intervention changes the optimal allocation of resources within periods. These results differ from the results of Garber and Phelps because their model implicitly assumes that future net resource use is zero and that current medical expenditures are independent of previous medical expenditures[3]. This effectively eliminates any role for intertemporal substitution of

[3] Phelps and Garber create these restrictions in two different ways in different parts of their paper. In a simple model in the beginning of the paper, individuals maximize $U_1(I_1 - H_1) + P_1(H_1) U_2(I_2 - H_2) + P_1(H_1) P_2(H_2) U_3(I_3)$ where I and H are income and health expenditures and utility depends on

income which is important because the possibility of intertemporal substitution implies that extensions in life will generate utility costs associated with spreading resources over a greater number of periods. This reduces the value of life extension by the present value of future net resource use weighted by the marginal utility of income. A similar result concerning valuations of the extension of life is reported by Rosen (1988) within the context of a model of lifetime utility maximization.

In assessing cost-effectiveness, interventions which generate a higher ratio will be preferred to those which generate a lower one. As Garber and Phelps (1992) demonstrate for a related problem, the equilibrium cost-effectiveness ratio will be equal to the reciprocal of the marginal utility of income. Specifically, substituting equations (6) and (7) into equation (8) implies that:

$$(9) \qquad CE = \frac{\dfrac{\partial E}{\partial m_{it}} + \sum\sum_{j\tau \neq it} \dfrac{\partial E}{\partial m_{j\tau}} \dfrac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T} \dfrac{\partial E}{\partial c_\tau} \dfrac{dc_\tau}{dm_{i\tau}}}{\lambda \dfrac{\partial E}{\partial m_{it}} + \lambda \sum\sum_{j\tau \neq it} \dfrac{\partial E}{\partial m_{j\tau}} \dfrac{dm_{j\tau}}{dm_{i\tau}} + \lambda \sum_{t=1}^{T} \dfrac{\partial E}{\partial c_\tau} \dfrac{dc_\tau}{dm_{i\tau}}} = \frac{1}{\lambda}$$

Thus the equilibrium cost-effectiveness ratio again equals the reciprocal of the marginal utility of income.

While equation (9) does allow for the adjustment of other medical inputs, which may be important due to the difficulty of identifying pure marginal effects of medical interventions, it also factors in changes in utility and expenditures which come about from sources such as changes in the optimal levels of consumption and unrelated medical expenditures which are not usually considered in

consumption (which is the difference between these) and the probability of survival through a period conditional upon reaching it depends only on current health expenditures. In this case, all future expenditures are independent of past expenditures since all income is spent in each period and the marginal product of expenditure on health is independent of past expenditures. This implies that all the terms which describe changes in future resource use in a CE formula such as (8) are zero. This means that future costs enter Equation (8) only through the first term in the numerator and, in fact, future costs drop out there as well because net resource use is assumed to be zero in each period. Presumably, then, one can define a cost-effectiveness criterion consistent with utility maximization which does not depend on future costs. However, since current medical interventions almost always have significant implications for the value of future medical interventions and since optimal life-cycle allocation of resources generally does not involve the consumption of all resources in every period, the assumptions necessary to generate this result are quite restrictive. In a later section of the paper, they relax the assumption that net resource use is zero within each period but implicitly impose the condition that the net present value of future resource use is zero by imposing a condition derived from a model in which people ignore future costs in a model in which people are supposed to consider future costs.

standard quality of life assessments. Since these effects may be difficult to measure, it would clearly be desirable to know whether some of these changes in other expenditures might be safely neglected.

In order to gain some insight into this question, it is useful to rearrange equation (8) by bringing the denominator onto the left side and recalling that, in equilibrium, CE = 1/λ so that:

$$(10A)\quad \frac{\partial EU}{\partial m_{it}} + \sum_{j\tau\neq it}\sum \frac{\partial EU}{\partial m_{j\tau}}\frac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T}\frac{\partial EU}{\partial c_{\tau}}\frac{dc_{\tau}}{dm_{i\tau}} = \lambda\left[\frac{\partial E}{\partial m_{it}} + \sum_{j\tau\neq it}\sum \frac{\partial E}{\partial m_{j\tau}}\frac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T}\frac{\partial E}{\partial c_{\tau}}\frac{dc_{\tau}}{dm_{i\tau}}\right].$$

Collecting the terms related to the adjustment of each medical intervention and to consumption yields:

$$(10B)\quad \left[\frac{\partial EU}{\partial m_{it}} + \lambda\frac{\partial E}{\partial m_{it}}\right] + \sum_{j\tau\neq it}\sum\left[\frac{\partial EU}{\partial m_{j\tau}} + \lambda\frac{\partial E}{\partial m_{j\tau}}\right]\frac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T}\left[\frac{\partial EU}{\partial c_{\tau}} + \lambda\frac{\partial E}{\partial c_{\tau}}\right]\frac{dc_{\tau}}{dm_{i\tau}} = 0$$

which implies that the cost-effectiveness criteria implied by (8) is a linear combination of all the first order conditions implied by (6) and (7)[4]. Since both the first term and each term within the sums is zero, it follows that any of these terms involving the total derivatives can be dropped without violating the equality. The resulting equation can then be factored back into a form such as (10A) and expressed as a ratio such as (8), only now omitting the terms in (8) which involve those particular total derivatives. As before, this should equal the marginal utility of income at the optimum.

This result, which is essentially an application of the envelope theorem, is useful because it suggests that any set of adjustments in inputs for related illness can be factored in on the utility side as needed to match the scenario used to assess the change in quality of life. The only requirement is that the costs related to those changes in inputs then be counted on the cost side. The practical implications of this are quite intuitive: should we want to assess the cost-effectiveness of bypass as compared to

[4] An additional implication of this is that the cost-effectiveness of an expenditure of a given type is a necessary but not sufficient criterion for utility maximization. Note, however, that if each intervention is unique in the sense that the set of total derivatives $\{\frac{dm_{11}}{dm_{i\tau}} \ldots \frac{dc_{\tau}}{dm_{i\tau}}\}$ is not a linear combination of the sets of total derivatives for other interventions and if the budget constraint is exhausted, then the criterion that all interventions be cost-effective is a sufficient criterion for utility maximization since (10) can only hold in that case if each term in brackets equals zero since there are then exactly as many independent linear equations as there are unknowns.

angioplasty for angina, we assess quality of life with each revascularization procedure, and count both the cost of revascularization and any changes in the costs of medical management.

The difficulty of assessing multiple changes in expenditures resulting from a particular medical intervention argues for including the minimum number of adjustments in other inputs necessary to describe the difference between utility with and without the intervention. The envelope theorem result cited above suggests that any other terms can be left out without changing the result as long as adjustments in other inputs can be considered to take place optimally at the margin. In health care, however, the presence of insurance, asymmetric information, and imperfect information about the benefits of medical interventions suggest that other treatments may often not be at an optimum. This implies that neglecting secondary effects on such interventions could result in a significant misstatement of cost-effectiveness. Therefore, when an intervention has effects on other interventions such as hospitalization for which deviations from optimality may be large, it may often be important to include these changes in the cost-effectiveness calculation. The gains in accuracy resulting from including such effects would have to be weighed against the effort and measurement errors involved in attempting to include them.

This question of which adjustments in expenditures to include in the benefit and cost sides of the equation also relates in some sense to the idea of "related" and "unrelated" costs. For instance, because expenditures for closely related conditions are more likely to change substantially in response to an expenditure for a given condition, these large changes in expenditures cannot be accurately described as occurring at the margin (without a change in consumer surplus) and should be accounted for. Conversely, even if one would otherwise want to account for an adjustment in another expenditure because it was felt that the efficiency criteria for the above envelope criterion for the exclusion of future costs did not apply, that adjustment might be safely neglected if it were small enough. That may be largely determined by the pathophysiology of the diseases in question. It is in these ways that the idea of "related" and "unrelated" diseases again becomes relevant.

Valuing Non-market Time: Does Cost-Effectiveness Analysis Discriminate Against the Elderly?

Cost-effectiveness analysis has been criticized as discriminating against the elderly (Avorn, 1984). The idea of including unrelated medical expenditures, consumption and earnings in medical cost-effectiveness analysis understandably heightens this concern since groups such as the elderly who tend to have lower earnings and higher consumption of medical care will receive lower priority in the delivery of health services. Of course, even if net resource use is high, an altruistic society may reasonably choose to allocate additional health care resources to assist such individuals. Nevertheless, since resources are limited, it is important to fully count the costs of providing those health care resources since doing so implies that fewer resources are available for other health interventions, as well as all other purposes.

A particular concern in the application of cost-effectiveness analysis to the elderly is that older individuals may appear to be net consumers of resources yet produce substantial benefits through nonmonetary means. For example, retired individuals, as well as individuals heavily involved in child care or other activities in the home, may have very low earnings yet be extremely productive in terms of utility generated for themselves and others. Because the elderly generally have higher levels of morbidity and mortality than younger individuals, the emphasis of cost-effectiveness analysis on the potential of an intervention to generate additional years of life of high quality may tend to direct resources away from the elderly, and including future costs related to the extension of life while neglecting the value of time spent spent outside the labor force would only inappropriately reinforce such a pattern.

To examine the appropriate treatment of non-market time in cost-effectiveness analysis, it is useful to allow utility to depend on leisure (l_t) -- by which is meant both leisure in the traditional sense and work outside of the market, which may also increase utility. Similarly, if w_t is the wage rate, then earnings ($= (1-l_t)w_t$) will depend on the extent of labor force participation. This implies:

$$(11) \qquad EU = \sum_{t=1}^{T} \beta^t \, S_t(m_{11},..m_{Kt-1}) \; U_t(c_t, l_t, H_t(m_{11},..m_{Kt-1}))$$

$$(12)\ \sum_{t=1}^{T} [\frac{1}{1+r}]^t\ S_t(m_{11},..m_{Kt-1})\ (\ c_t + \sum_{j=1}^{K} m_{jt}) = I_1 + \sum_{t=1}^{T} [\frac{1}{1+r}]^t\ S_t(m_{11},..m_{Kt-1})\ (1-l_t)w_t$$

Maximizing (11) subject to (12) yields the following set of first order conditions for consumption, leisure, and medical interventions:

$$(13)\quad \beta^t S_t(m_{11},..m_{Kt}) \frac{\partial U_t(c_t,l_t,H_t(m_{11},..m_{Kt-1}))}{\partial c_t} = \lambda \{ [\frac{1}{1+r}]^t S_t(m_{11},..m_{Kt-1}) \} \qquad t = 1...T$$

$$(14)\quad \beta^t S_t(m_{11},..m_{Kt-1}) \frac{\partial U_t(c_t,l_t,H_t(m_{11},..m_{Kt-1}))}{\partial l_t} = -\lambda \{ [\frac{1}{1+r}]^t S_t(m_{11},..m_{Kt-1}) w_t \} \quad t = 1...T$$

$$(15)\ \sum_{\tau=t}^{T} \beta^\tau \Big[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}} U_\tau(c_\tau,l_\tau,H_\tau(m_{11},..m_{K\tau-1})) + S_\tau(m_{11}..m_{K\tau-1}) \frac{\partial U_\tau(c_\tau,l_\tau,H_\tau(m_{11},..m_{K\tau-1}))}{\partial m_{it}} \Big]$$

$$= \lambda \{ [\frac{1}{1+r}]^t S_t(m_{11}..m_{K\tau-1}) + \sum_{\tau=t}^{T} [\frac{1}{1+r}]^\tau \Big[\frac{\partial S_\tau(m_{11}..m_{K\tau-1})}{\partial m_{it}} [c_\tau + \sum_{j=1}^{K} m_{j\tau} - (1-l_\tau) w_\tau] \Big] \qquad i = 1...K, t = 1...T$$

These differ from the previous set of first order conditions only in the dependence of future utility and earnings on the amount of leisure chosen, and the addition of a set of first order conditions to describe the decision concerning leisure, whereby increases in utility from greater leisure are traded off against lost earnings. The cost-effectiveness ratio is a simple extension of equation (8), with an additional term added to the numerator and denominator to reflect the changes in costs and utility which occur when time spent in leisure adjusts to the changes resulting from the medical intervention.

$$(16)\qquad CE = \frac{\frac{dE}{dm_{it}}}{\frac{dEU}{dm_{it}}} = \frac{\frac{\partial E}{\partial m_{it}} + \sum\sum_{j\tau\neq it} \frac{\partial E}{\partial m_{j\tau}} \frac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T} \frac{\partial E}{\partial c_\tau} \frac{dc_\tau}{dm_{i\tau}} + \sum_{t=1}^{T} \frac{\partial E}{\partial l_\tau} \frac{dl_\tau}{dm_{i\tau}}}{\frac{\partial EU}{\partial m_{it}} + \sum\sum_{j\tau\neq it} \frac{\partial EU}{\partial m_{j\tau}} \frac{dm_{j\tau}}{dm_{i\tau}} + \sum_{t=1}^{T} \frac{\partial EU}{\partial c_\tau} \frac{dc_\tau}{dm_{i\tau}} + \sum_{t=1}^{T} \frac{\partial EU}{\partial l_\tau} \frac{dl_\tau}{dm_{i\tau}}}\ .$$

Increases in leisure are counted on the utility side by entering into the utility function in all the terms and by the adjustments in leisure in response to the changes in medical expenditures. Likewise, leisure affects costs through its effects on lifetime earnings which change as mortality changes in response to medical interventions and through the adjustments in the chosen level of leisure in response to the changes in medical expenditures. It is difficult to know how these issues related to the valuation of leisure may bias existing approaches to cost-effectiveness analysis since the value of leisure is not currently accounted for explicitly in either costs or benefits. For example, it is not clear to what extent individuals may reflect concerns about changes in leisure time (or resource use) in answering questions used to elicit assessments of quality of life from the time tradeoff, standard gamble, or other methods of quality of life assessment. Presumably a day of severe flu symptoms which prevents someone from going to work is a bad thing, but a day of severe flu symptoms would be even less pleasant if one still went to work. Similarly, epidemiologic studies of quality of life show significant declines with age (Fryback et al. 1993), but might show even greater declines with age if the concomitant increases in leisure were not reflected to some extent in older individuals' assessments of their quality of life.

While this extension of the model does capture the benefits to an individual of time spent in non-market activites, it is important to recognize that it does not capture the benefits derived by others from an individual's contributions through non-market activities. This may be particularly important among the elderly because their greater likelihood of being disabled or having a disabled spouse makes them more likely than individuals of other ages to be either large consumers or large producers of informal care services. Thus there is likely to be a particularly large degree of heterogeneity in net resource use among the elderly that is not captured by data on the consumption and production of market goods.

Section II: Empirical Implications

Given the gap between these theoretical concerns about the appropriate measurement of costs and the current practice of cost-effectiveness analysis, it is important to get a sense of the magnitude of the effect of including future costs on the cost-effectiveness of different interventions. As indicated above, several studies already account for future costs for related illnesses. Examples include the Coronary Heart Policy Model (Weinstein, et al. 1987) and the Randomized Intervention Treatment of Angina (RITA) trial (Schulpher, et al. 1994). In the RITA trial, attention to future costs has shown that while angioplasty may reduce initial costs for the treatment of angina by 50% compared to CABG, the greater need for subsequent procedures decreases those savings to only 20% after two years. This has caused the trial to be continued to evaluate whether total costs may actually be higher for angioplasty patients in the long run.

In contrast, there appear to be only a few studies which have attempted to account for future unrelated medical costs, and none that have fully accounted for effects on earnings and consumption. Studies that have included future unrelated medical costs include Stason and Weinstein's 1977 study of the treatment of hypertension and two studies performed by the Office of Technology Assessment (OTA) in the early 1980s examining vaccination against pneumococcal pneumonia (Willems 1980) and influenza (OTA 1981). The pneumococcal vaccine study only reported results that include future medical costs for unrelated illnesses. However, the influenza study reported results both with and without future unrelated costs, and found that including future costs generated as a result of vaccination substantially changed both the absolute cost-effectiveness and the relative cost-effectiveness between age and risk groups. The results of the analysis are summarized in Table 1. When future medical costs are ignored, vaccination appears far more cost-effective for older than for younger and for high-risk than for low-risk individuals. When the higher future medical costs of older and higher-risk patients are added, vaccination becomes about half as cost-effective for high-risk individuals as for low-risk individuals, and is actually less cost-effective for older high-risk individuals than for younger high-risk individuals. Perhaps more important than the changes in relative cost-effectiveness of vaccination when future costs are included is the fact that vaccination appears to be cost-effective in all age and risk groups when compared to common preventive medical interventions such as the control of hypertension, and screening for cervical cancer. Interestingly, the OTA report seemed to favor the formulation omitting future medical costs, concluding: "influenza vaccination is a low-cost preventive medicine intervention that yields benefits in all groups. Influenza vaccination appears to be most cost-effective among high risk groups." To this date, official policy still targets immunization to older and high-risk individuals, and does not explicitly advise immunization for the general public.

Since influenza vaccination compares favorably to many interventions considered cost-effective regardless of whether one includes future medical costs, the recommendation not to promote more widespread vaccination represents more a problem of misinterpretation of results than of false conclusions based on an unawareness of implications for future medical costs. However, there may also be cases in which an intervention which appears cost-effective when future costs are ignored but is no longer cost-effective when future costs are accounted for. Whether this is actually the case will depend on the magnitude of those future costs.

Future Unrelated Medical Costs, Consumption, and Earnings: Costs per Life Year

The theoretical discussion above concludes that cost-effectiveness analyses from a utility maximization perspective should consider not only medical expenditures but also consumption and earnings. Ideally, estimates of these costs for different interventions should reflect the specific characteristics of individuals likely to receive the intervention. For example, an assessment of the cost-effectiveness of a hypothetical treatment for schizophrenia which reduces the rate of suicide without affecting labor force participation or earnings among survivors should use the earnings of individuals with schizophrenia rather than average earnings of all individuals. Future work will have to assess such costs for individual clinical situations.

As an interim approach to the estimation of these future costs, it is useful to consider the value of future costs in the general population. Figure 1 plots average consumption, medical expenditures and earnings by age past age 25 as well as the net resources consumed (i.e. c+m-e). Consumption by age is drawn from the Consumer Expenditure Survey (1990-91), and excludes medical expenditures and payments into pensions and insurance policies. Medical expenditures are taken from Waldo (1989), and reflect all personal health care expenditures including hospital, physician, nursing home and others public and private expenditures. Earnings are determined from the Current Population Survey (1992) and are adjusted to a per capita basis for labor force participation. These are all adjusted to 1993 dollars using the medical and consumer price indexes.[5]

While consumption rises slowly until age 65 and then declines slightly and medical expenditures demonstrate a steady upwards trend towards a maximum of $10,000, the greatest change by age is for earnings, which fall from approximately $23,000 per year before age 65 to $3000 per year after age 65. The consequence for net resource use is that it rises gradually from -$12,000 per year at age 25 to +$18,000 per year past age 65.

In order to begin to assess the effects of including future costs on the cost-effectiveness of medical interventions, it is useful to consider the case in which an intervention results in an immediate reduction in mortality at the time it is carried out. In that case, changes in mortality at a given age will result in the generation of future net resource use proportional to the expected present value of net resource use past that age as well as an increase in life expectancy proportional to life expectancy at that age. Figure 2 plots the net resource cost of life extension per year of life saved by age. This is the additional cost per year of life saved which needs to be considered when adjusting for future costs when an intervention decreases mortality at that age. To maintain comparability with the cost-effectiveness literature, both costs and benefits are discounted at 5% annually. Since preventing death at a given age implies that death may then occur at any future age, this profile is smoothed somewhat relative to the profile for net resource use by age. Nevertheless, there is still a difference of approximately $20,000 per year between 45 year-olds and 65 year-olds and $30,000 between 25 year-olds and 85 year-olds.

5 Since the medical consumer price index is known to suffer from a variety of measurement problems (Newhouse 1992), all calculations were repeated using the overall consumer price index for comparison. There were no substantive changes in the results.

When cost effectiveness is measured in cost per life-year saved, extremely cost-effective interventions, such as influenza vaccination, will generally continue to compare favorably to other common medical interventions even when future costs are considered, but the key question is whether there are other interventions for which this may not be the case. To judge this, one needs a sense of what level of cost-effectiveness is required to consider an intervention cost-effective. There is surely no absolute standard for this. Nevertheless, Goldman et al. (1992) present what seems to be a reasonable view on the subject by observing that most currently accepted interventions tend to have cost-effectiveness ratios less than $40,000 per quality-adjusted life year while cost-effectiveness ratios above $60,000 are higher than accepted programs and ratios greater than $100,000 are generally unacceptable. Table 2 reports the cost per life year for a number of possible interventions. Remembering that the table reports the cost per life year as opposed to the cost per quality-adjusted life year, as Goldman discusses, his generalization seems to hold fairly well in the sense that interventions which cost less than $40,000 per year uniformly are considered a minimum standard of care while those between $40,000 per year and $100,000 per year are considered more questionable and those above that level are generally considered not to be cost-effective and tend not to be part of routine practice. Despite this general correlation between calculated cost-effectiveness and extent of use, it is worth noting that it is not at all clear that the studies of cost-effectiveness were influential in determining the breadth of use.

Even assuming some connection between the estimated cost-effectiveness of a procedure and its use, the width of this band within which procedures may or may not be part of routine practice suggests that there are not likely to be many procedures for which a $20,000 or $30,000 change in costs due to the inclusion of future costs will make the difference in whether it is considered cost-effective. Reinforcing this is the fact that the difference of $20,000 or $30,000 per year reflects interventions with reductions in mortality at a single age. Since preventive health care interventions will tend to reduce mortality over a range of ages and to extend years of life past retirement where there is less variation in average net resource use by age, the actual discounted costs will reflect an average of values which themselves show even less variation. Therefore unrelated net resource use is likely to vary by substantially less than $20,000 or $30,000 across ages for many interventions.

Future Medical Costs, Consumption, and Earnings: Costs per Quality-Adjusted Life Year

The above estimates refer to the cost per life year saved, rather than the cost per quality-adjusted life year saved. As discussed in the theoretical section above, since medical interventions may potentially have much greater effects on life expectancy than on quality adjusted life expectancy, it is possible that the effect of future costs on the cost per quality adjusted life year can be much larger than the effect on the cost per life year. To determine the effect of including future costs precisely requires that an investigator implement equations such as (5) and (8) by building all future costs directly into the decision model. The results of this analysis suggest that this should become standard practice in medical cost-effectiveness analysis.

For studies which have already been published, it should generally not be difficult to modify the model to account for future costs (Johannesson, Meltzer and O'Conor 1996). In the interim, an alternative approach is to estimate the bias due to the omission of future costs by using an approximation that is based on the effects of an intervention on life expectancy and quality-adjusted life expectancy, since existing cost-effectiveness analyses sometimes report both of these results. For this approximation to be reasonably accurate, it must be the case that the mortality changes resulting from an intervention are concentrated at the time of the intervention and that annual future costs are roughly constant (=C). In that case, future costs are C*ΔLE and the cost-effectiveness ratio can be written as:

$$(17) \qquad CE = \frac{\Delta \text{cost}}{\Delta \text{QALY}} = \frac{\Delta \text{present cost}}{\Delta \text{QALY}} + \frac{\Delta \text{future cost}}{\Delta \text{QALY}} = \frac{\Delta \text{present cost}}{\Delta \text{QALY}} + C^* \frac{\Delta \text{LE}}{\Delta \text{QALY}} .$$

The first term in this expression is the traditional definition of cost-effectiveness, while the second term describes the future costs which are commonly omitted. Thus the bias in current calculations is

$- C^* \frac{\Delta LE}{\Delta QALY}$. Annual future costs (C) can be approximated at any age by the net present value of future resource use per year of life from that age on, as is displayed in Figure 2, and ΔLE and $\Delta QALY$ can be found in some published cost-effectiveness analyses.

Since equation (17) is an approximation, its validity will have to be documented by future investigation. Nevertheless, it is a useful illustration of the potential bias due to the omission of future costs. Since cost effectiveness is not an issue if an intervention does not improve quality adjusted life expectancy, the equation is only relevant when $\Delta QALY > 0$. However, both C and ΔLE can be either positive or negative and ΔLE can be less than or greater than $\Delta QALY$ so the bias term can be zero, positive or negative and greater than or less than C. For example, when there are no effects on survival so ΔLE is zero, the bias is zero. In the more common case that there are positive effects on life expectancy, the bias will be downward in older populations with positive net future costs. This generates the result that current methods for cost-effectiveness analysis are biased to favor interventions that extend life over interventions that improve its quality. For example, current methods for cost-effectiveness analysis would favor treatment of prostate cancer over total knee replacement. In younger populations where net future resource use is still negative, the bias will go in the opposite direction, but since most health care interventions are in the elderly, this may be of lesser importance.

Table 3 uses this approximation to estimate the effect of including future "unrelated" costs on the cost-effectiveness of a range of medical interventions. The magnitude of the bias due to the omission of future costs depends on both the magnitude of C at the age in question and the ratio of effects on life expectancy and quality-adjusted life expectancy. Figure 2 shows that C varies from -$10,000 per year at age 25 to +$20,000 per year at age 85. Table 3 reports results based on the value of C at the age at which the intervention took place. As noted above, this would generate correct estimates of future costs only if all changes in mortality resulting from an intervention were concentrated at the time of the intervention and if annual future costs were constant. Since reductions in mortality resulting from an intervention are more likely to be spread over a range of years following the intervention and since annual future costs per year of life saved rise continuously with age, this approach will tend to underestimate the future costs associated with medical interventions which reduce mortality. The magnitude of this underestimation will vary both with age and with the degree of delay in the reductions in mortality resulting from the medical intervention.

Table 3 demonstrates that the ratio of changes in life expectancy to changes in quality-adjusted life expectancy depends on the specific intervention in question. For interventions such as the treatment of hypertension with few negative effects on quality of life, the ratio of life expectancy to quality-adjusted life expectancy is about one, while for adjuvant chemotherapy for node-negative breast cancer the ratio is about two and for adjuvant chemotherapy for Duke's C colon cancer, it is as high as 18. One issue worth keeping in mind is that most of the papers cited reported changes in discounted quality-adjusted life years, but do not discount changes in life expectancy. If all reductions in mortality were immediate, this would not cause a problem in the estimation of futue costs. However, if there are delayed reductions in mortality, this practice might tend to inflate the ratio of changes in life-expectancy to changes in quality adjusted life expectancy and therefore the bias associated with the omission of future costs. Thus there are both upwards and downwards biases associated with this method of estimating future costs. It is not clear a priori which will dominate.

Given these caveats, Table 3 illustrates several examples of the bias which can result from the omission of future costs. First, for each intervention, the omission of future unrelated costs artificially lowers the cost per QALY for the older groups substantially relative to the younger groups. This is illustrated by the cost-effectiveness of the treatment of severe hypertension in 40 year-old and in 50 year-old men. Ignoring future costs, the treatment of hypertension is only slightly more cost-effective in 40 year-olds than in 50 year-olds ($18,000/QALY vs $25,000/QALY). Including future costs widens the gap substantially to $12,800/QALY vs $25,000/QALY between the two age groups. A second point illustrated by the table is that these effects are larger for interventions which increase the length of life more than the quality of life. This is well illustrated by the case of adjuvant chemotherapy for node-negative breast cancer in women aged 45 and in women aged 60, which differ little in cost-effectiveness when future costs are ignored ($18,000/QALY vs $21,000/QALY), but by a factor of four ($9,300/QALY vs $36,400/QALY) when future costs are included. Likewise, looking only at 60 year-olds, accounting for the effects on future costs dramatically changes the relative cost-effectiveness of the treatment of hypertension, adjuvant chemotherapy for colon cancer and hemodialysis. Ignoring future costs, the treatment of hypertension and adjuvant chemotherapy for Duke's C colon cancer are comparable in cost-effectiveness at $60,000/QALY and $67,000/QALY, and more attractive than dialysis at $117,000/QALY. Including future costs dramatically increases the cost per QALY associated with adjuvant chemotherapy for colon cancer, while having relatively little effect on the cost-effectiveness of hemodialysis or the treatment of hypertension. This is because adjuvant chemotherapy achieves relatively more of its benefits from extending life than improving its quality compared to the benefits obtained from the treatment of hypertension, or even hemodialysis, as demonstrated by the ratio of changes in life expectancy to changes in quality adjusted life expectancy. The result is that hemodialysis then becomes substantially more cost-effective than adjunctive chemotherapy ($129,000/QALY vs $211,000/QALY), with the treatment of hypertension by far the most cost-effective at $68,500/QALY.

Among the interventions examined in this table, the ratio of changes in life expectancy to changes in quality-adjusted life expectancy seems to be particularly high for the case of adjunctive chemotherapy in Duke's C colon cancer. However, there are other instances in which the ratio of changes in life expectancy to changes in quality adjusted life expectancy also appears to be quite high. For instance, the optimistic scenarios in the analysis of the treatment of clinically localized moderately differentiated prostate cancer by Fleming et al. (1993) suggest ratios of life expectancy to quality-adjusted life expectancy ranging from around 2 to 5. For 65 year-old men, the LE/QALE ratio for radiation therapy (XRT) is 3.5 which, with a future cost at age 65 of about $17,000 per year, suggests that the cost per QALY of XRT would be about $60,000 per quality-adjusted life year even if the treatment itself were free. Thus, accounting for future unrelated costs significantly strengthens the results of the study by suggesting that treatment is unlikely to be highly cost-effective even in the optimistic scenarios in which treatment is relatively successful. The magnitude of these effects suggests that further review of the cost-effectiveness literature seems likely to reveal other instances in which accounting for future costs significantly influences the findings concerning the cost-effectiveness of medical interventions.

Section III - Conclusions

The theoretical section of this paper demonstrates that cost-effectiveness criteria for the allocation of medical expenditures are strictly consistent with a model of lifetime utility maximization only if they account for effects on future related and unrelated medical expenditures, as well as consumption and earnings. This is a potentially important finding since it is not common practice to include these costs in medical cost-effectiveness analysis and since there has been theoretical disagreement as to whether they should be included. Changes in the levels of future expenditures conditional on survival may be neglected in most instances, but should be included if they are reflected in the approach used to assess quality of life, are too large to be considered changes taking place at the margin, or if there are reasons to expect these allocations to deviate significantly from efficient ones.

The empirical section that follows suggests that the magnitude of unrelated medical expenditures, consumption and earnings may be large enough to substantially alter the cost-effectiveness of common medical interventions, especially where an intervention has greater effects on life expectancy than on quality adjusted life expectancy. This implies that existing cost-effectiveness analyses are generally biased to favor interventions that extend the length of life over interventions that improve its quality and suggests that all future costs should be routinely included in cost-effectiveness analyses. There is much work to be done in reviewing existing studies to determine how accounting for future costs is likely to affect their findings. Nevertheless, limitations on the ability to accurately estimate the bias due to the omission of future costs using the data published in most cost-effectiveness analyses suggests that reliable estimation of the effects of future costs on cost-effectiveness may require directly incorporating future costs into the models used to calculate cost-effectiveness.

From its foundation in utilitarian philosophy through its potential to interfere in the patient-physician relationship, cost-effectiveness analysis has always raised a myriad of difficult ethical issues (LaPuma and Lawlor, 1990). The inclusion of "unrelated" future costs in cost-effectiveness analyses adds to this set of important issues concerning the ethical basis of cost-effectiveness analysis. Even though our society seems willing to provide tacit approval of inequality in access to health care by income and wealth, the prospect of explicitly rationing medical services according to socioeconomic characteristics such as future earnings forces us to confront this issue more directly. Are we willing to endorse a system of resource allocation in which diseases of the poor and elderly receive lower priority simply because they are diseases of the poor or elderly? Indeed, many analysts prefer cost-effectiveness analysis to cost-benefit and willingness to pay analysis specifically because it does not allow individual variations in willingness to pay to influence decisions about health care utilization. By including non-medical costs, the approach discussed here moves cost-effectiveness closer to cost-benefit or willingness-to-pay analysis and their associated concerns about tradeoffs between equity and efficiency. Formal approaches towards the consideration of equity and efficiency, such as social welfare analysis, may provide some guidance (Wagstaff, 1991), but will not obviate the need for basic discussions about individual and social values concerning health, equity, efficiency and choice. As painful as such discussions may be, it seems preferable to have them openly than to hide value judgements behind imprecise analytic techniques with unclear distributional and efficiency implications. That ignoring future costs tends to redistribute resources towards the elderly but at the cost of artificially favoring interventions that increase the length of life over interventions that improve its quality speaks to the danger of using analytic imprecision to accomplish social objectives.

Increased attention to the cost side of cost-effectiveness analysis will also demand more precision in the consideration of the benefit side, and the evaluation of quality of life in particular. For example, the ambiguities concerning the extent to which individuals factor in the value of changes in leisure associated with changes in health status when answering questions designed to assess the quality of life raises the possibility of systematic biases in assessing the utility associated with different ages and with different health states. Determining to what extent these variations in labor force participation may already be factored into individual's assessments of their quality of life in different states of disability is an extremely important area for further investigation. Likewise, it is not clear to what extent people might reflect concerns about the intertemporal substitution of income in answering time trade-off questions sometimes used to assess the quality of life. These are only a few of the many important questions concerning the validity of existing approaches to quality of life assessment. Finally, the value of individuals' health to other individuals - whether through non-market activities or, probably more importantly, through altruistic links - must also be considered. Though it is obviously difficult to know how to estimate such valuations, they may be an extremely important aspect of the desire to devote resources to health care.

It is not difficult to understand why the use of cost-effectiveness analysis for the allocation of health care resources has been controversial, but the imperative to control health care costs in the face of ever-increasing technological possibilities and the absence of strong alternatives for the allocation of resources make it important that the investigation of its theoretical foundations continue.

Table 1

Cost-effectiveness of Influenza Vaccination
(cost per year of life saved)

	Low Risk Population		High Risk Population	
Age	w/o future med costs	w/ future med costs	w/o future med costs	w/ future med costs
<3	258	1745		
3-14	196	1880		
15-24	181	2010	44	3050
25-44	64	2027	23	3620
45-64	23	2084	15	4150
≥65	< 0	1782	< 0	4040

Costs in 1979 Dollars

Office of Technology Assessment, 1981

Table 2
Cost Effectiveness of Common Medical Interventions

Intervention	Cost/Life Year
Neonatal PKU Screening Bush et al. (1973)	<0
Secondary Prevention of Hypercholesterolemia in Men Ages 55-64 Goldman et al. (1991)	2000
Secondary Prevention of Hypercholesterolemia in Men Ages 65-74 Goldman et al. (1991)	13000
Pap Smear Every 3 Years - Ages 20-74 Eddy (1990)	17000
Treatment of Severe Hypertension (Diastolic 105 mmHg and above) Stason and Weinstein (1977)	17000
Annual Breast Exam 55-64 Eddy (1989)	14000-27000
Annual Breast Exam 65-74 Eddy (1989)	17000-30000
Secondary Prevention of Hypercholesterolemia in Men Ages 75-84 Goldman et al. (1991)	25000
Annual Breast Exam 40-50 Eddy (1989)	25000-58000
Mammography 55-64 Compared to Breast Examination Eddy (1989)	28000-106000
One Time Physical Exam for Abdominal Aortic Aneurism Frame et al. (1993)	29000
Treatment of Mild Hypertension (Diastolic 95-104 mmHg) Stason and Weinstein (1977)	34000
One Time Ultrasound for Abdominal Aortic Aneurism Frame et al. (1993)	42000
Mammography 65-74 Compared to Breast Examination Eddy (1989)	45000-163000
Mammography 40-50 Compared to Breast Examination Eddy (1989)	52000-237000
Primary prev., severe hyperchol., mod. obese, non-smoking, normotensive male 55-64 Goldman et al. (1991)	60000
Primary prev., mod. hyperchol., mod. obese, non-smoking, normotensive male 55-64 Goldman et al. (1991)	99000
Screening Exercise Test in Asymptomatic 40 Year-old Males Sox (1989)	124000
Pap Smear Every 2 Years Compared to every 3 years - Ages 20-74 Eddy (1990)	258000
Physical Exam every 5 years for Abdominal Aortic Aneurism Frame et al. (1993)	747000
Pap Smear Year Compared to every 2 years - Ages 20-74 Eddy (1990)	833000
Ultrasound every 5 years for Abdominal Aortic Aneurism Frame et al. (1993)	907000

Future costs included only for related interventions, and discounted at 5%
Costs converted to 1993 dollars using the medical CPI (Monthly Labor Review, Bureau of Labor Statistics)

Table 3

Effect of Future "Unrelated" Costs on the Cost per Quality Adjusted Life Year

Intervention	Change in LE	Change in QALE	Change in LE/QALE	Annual Future Cost (C)	Bias due to Future Cost	Reported Cost/QALY	Actual Cost/QALY
Adjuvant Chemotherapy for Duke's C Colon Cancer Age 55 Smith et al. (1993)	2.4 yr	0.4 yr	6.00	3000	18000	16700	34700
Treatment of Severe Hypertension Men Age 40* Stason and Weinstein (1977)	4 yr	3.9 yr	1.03	-5000	-5200	18000	12800
Adjuvant Chemotherapy for Node-Negative Breast Cancer Age 45 Hillner and Smith (1991)	11 mo	5.1 mo	2.16	-4000	-8700	18000	9300
Adjuvant Chemotherapy for Node-Negative Breast Cancer Age 60 Hillner and Smith (1991)	7.7 mo	4.0 mo	1.93	8000	15400	21000	36400
Treatment of Severe Hypertension Men Age 50* Stason and Weinstein (1977)	2.6 yr	2.5 yr	1.04	0	0	25000	25000
Coronary Artery Bypass 3 Vessel Disease, Mild Angina Age 55 Wong et al. (1990)	0.6 yr	0.7 yr	0.86	3000	2600	31000	33600
Coronary Artery Bypass 3 Vessel Disease, Severe Angina Age 55 Wong et al. (1990)	1.4 yr	1.4 yr	1.00	3000	3300	45000	48300
Adjuvant Chemotherapy for Node-Negative Breast Cancer Age 75 Desch, Hillner, Smith and Retchin (1993)	2.9 mo	1.8 mo	1.61	20000	32200	54000	86200
Hormone Replacement Therapy Ages 55-65 Tosteson and Weinstein (1991)	.0458 yr	.0387 yr	1.18	8000	9400	54200	63600
Treatment of Severe Hypertension Men Age 60* Stason and Weinstein (1977)	1.5 yr	1.4 yr	1.07	8000	8500	60000	68500
Adjuvant Chemotherapy for Duke's C Colon Cancer Age 60 Estimated based on Smith et al. (1993)**	1.8 yr	0.1 yr	18.00	8000	144000	67000	211000
Hemodialysis for ESRD Men Aged 30 Estimated based on Garner et al. (1987) and Hornberger et al. (1992)***	.	.	1.50	0	0	117000	117000
Hemodialysis for ESRD Men Aged 60 Estimated based on Garner et al. (1987) and Hornberger et al. (1992)***	.	.	1.50	8000	12000	117000	129000

Costs converted to 1993 dollars using the medical CPI (Monthly Labor Review, Bureau of Labor Statistics).

* Stason and Weinstein already include future unrelated medical costs, so the additional future costs here refer only to consumption net of earnings.

** Estimates made for 60 year-olds assuming a life expectancy of 16 years at age 60 as opposed to 20 years at age 55 used to calculate the cost-effectiveness at age 55.

*** Cost-effectiveness estimates based on Garner et al. (1987) using quality of life estimates from Hornberger et al. (1992)

Appendix 1: Arrow-Debreu Equilibrium

To describe the Arrow-Debreu equilibrium, let $\vec{\varepsilon}_t = \{\varepsilon_{11} \ldots \varepsilon_{tj} \ldots \varepsilon_{tJ}\}$ be the history of health shocks across all J individuals to time t, where each ε_{tj} can take on any of a discrete number of values. Accordingly, $p(\vec{\varepsilon}_t)$ is the probability of the occurrence of history $\vec{\varepsilon}_t$. Likewise represent consumption and medical expenditure for intervention k (=1,..K) of individual j at time t given history $\vec{\varepsilon}_t$ as $c_{tj}(\vec{\varepsilon}_t)$ and $m_{tjk}(\vec{\varepsilon}_t)$ and the individual's full history of medical expenditures at time t as $\vec{m}_{tj}(\vec{\varepsilon}_t) = \{m_{1j1}(\vec{\varepsilon}_t), \ldots m_{1jk}(\vec{\varepsilon}_t), \ldots m_{tjK}(\vec{\varepsilon}_t)\}$. Using this notation, we define an individual's health and survival at time t for each history as $H_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))$ and $S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))$ where S_{tj} equals 1 if the individual is alive and is zero otherwise. Adopting an expected utility formulation of the utility function and history-specific resource constraints which allow for savings across periods yields:

$$(1) \qquad EU = \sum_{j=1}^{J} \sum_{t=1}^{T} \sum_{\{\vec{\varepsilon}_t\}} \beta^t p(\vec{\varepsilon}_t)\, S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\, U_{tt}(c_{tj}(\vec{\varepsilon}_t), H_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))$$

$$(2) \quad \sum_{j=1}^{J} S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\,(c_{tj}(\vec{\varepsilon}_t) + \sum_{j=1}^{K} m_{tj}(\vec{\varepsilon}_t)) + K_t(\vec{\varepsilon}_t) \;=\; (1+r)\, K_{t-1}(\vec{\varepsilon}_{t-1}) + \sum_{j=1}^{J} S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\, i_{tj}$$

for all $\vec{\varepsilon}_t$ where $K_t(\vec{\varepsilon}_t)$ is the aggregate savings at time t for history $\vec{\varepsilon}_t$.

Maximizing 1 subject to 2 should yield the Arrow Debreu-equilibrium, however this cannot be solved with standard techniques because the functions are not continuous since $S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))$ equals either zero or one, so that its derivatives with respect to m are not defined. This problem of discontinuities in Arrow - Debreu programs can be addressed by reformulating the problem in terms of lotteries, as suggested by Prescott and Townsend (1984), Hansen (1985), Townsend (1986). Specifically, we define a set of lotteries over c, m, H, and S, where each is allowed take on a finite number of values and the probability of a given outcome is given by:

$$\Pi_{tj}((c_{tj}(\vec{\varepsilon}_t), \vec{m}_{tj}(\vec{\varepsilon}_t), H_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t)), S_{tj}((\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))) = \Pi_{tj}(c_{tj}, \vec{m}_{tj}, H_{tj}, S_{tj}, \vec{\varepsilon}_t)$$

where $\sum_{\{c\, m\, H\, S\}} \Pi_{tj}(c_{tj}, \vec{m}_{tj}, H_{tj}, S_{tj}, \vec{\varepsilon}_t) = 1$ for all $\vec{\varepsilon}_t$. This formulation then yields the following utility function and budget constraint:

$$(1) \qquad EU = \sum_{j=1}^{J} \lambda^{j} \{ \sum_{t=1}^{T} \sum_{\{\vec{\varepsilon}_t\}} \sum_{\{c\ m\ H\ S\}} \beta^{t}\ \Pi_{tj}(c_{tj}, \vec{m}_{tj}, H_{tj}, S_{tj}, \vec{\varepsilon}_t)\ S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\ U_{tj}(c_{tj}(\vec{\varepsilon}_t), H_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t)) \}$$

$$(2) \quad \sum_{j=1}^{J} \sum_{\{c\ m\ H\ S\}} \Pi_{tj}(c_{tj}, \vec{m}_{tj}, H_{tj}, S_{tj}, \vec{\varepsilon}_t)\ S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\ (c_{tj}(\vec{\varepsilon}_t) + \sum_{j=1}^{K} m_{tj}(\vec{\varepsilon}_t)) + K_t(\vec{\varepsilon}_t)$$

$$= (1+r)\ K_{t-1}(\vec{\varepsilon}_{t-1}) + \sum_{j=1}^{J} \sum_{\{c\ m\ H\ S\}} \Pi_{tj}(c_{tj}, \vec{m}_{tj}, H_{tj}, S_{tj}, \vec{\varepsilon}_t)\ S_{tj}(\vec{\varepsilon}_t, \vec{m}_{tj}(\vec{\varepsilon}_t))\ w_{tj}$$

for all $\vec{\varepsilon}_t$ where $K_t(\vec{\varepsilon}_t)$ is the aggregate savings at tine t for history $\vec{\varepsilon}_t$ and λ^j are person-specific utiliity weights. Proof of the existence and optimality of an equilibrium solution to this problem is a direct application of the results in Prescott and Townsend (1984).

Figure 1
Consumption, Medical Expenditures, Earnings and Net Resource Use by Age

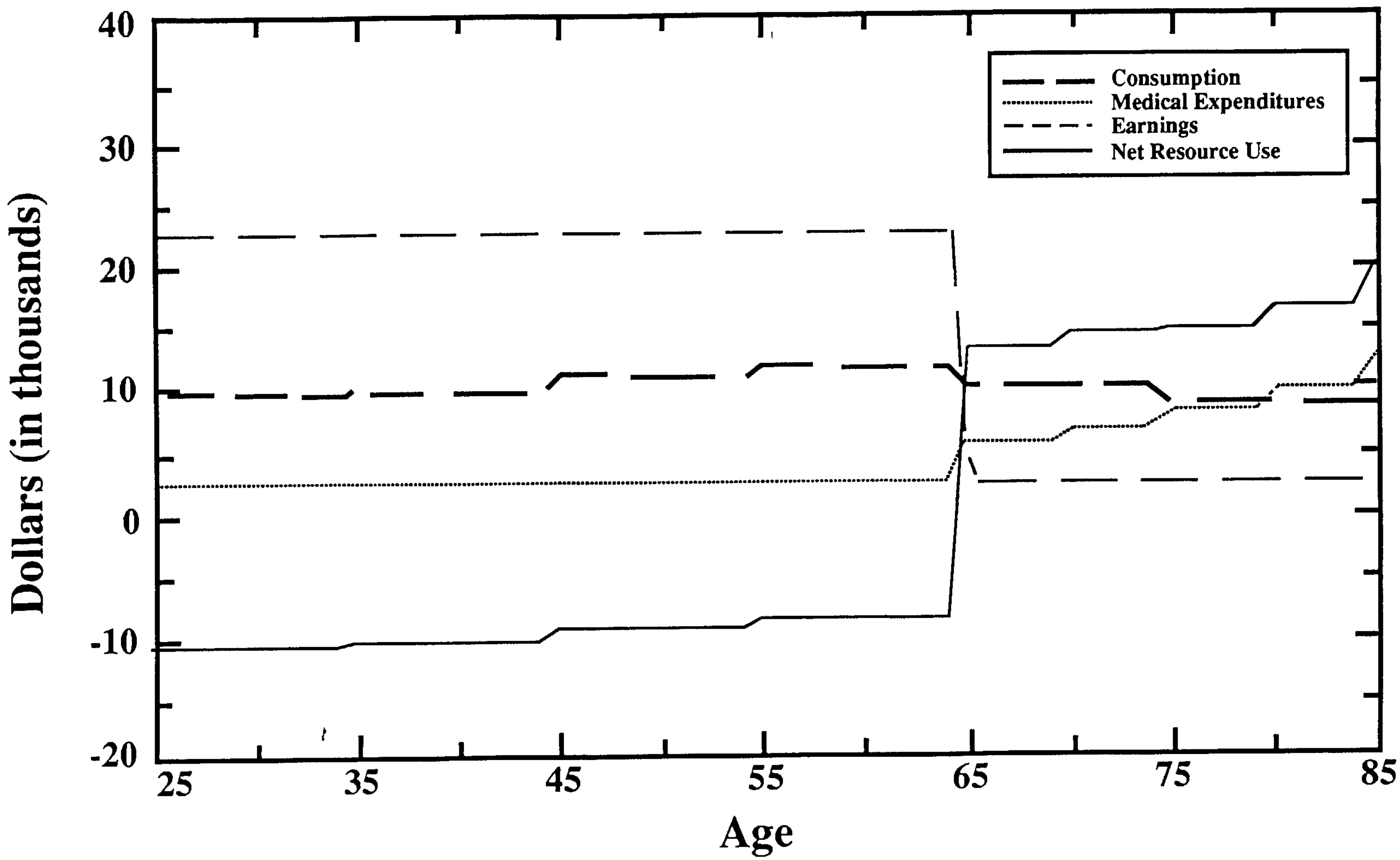
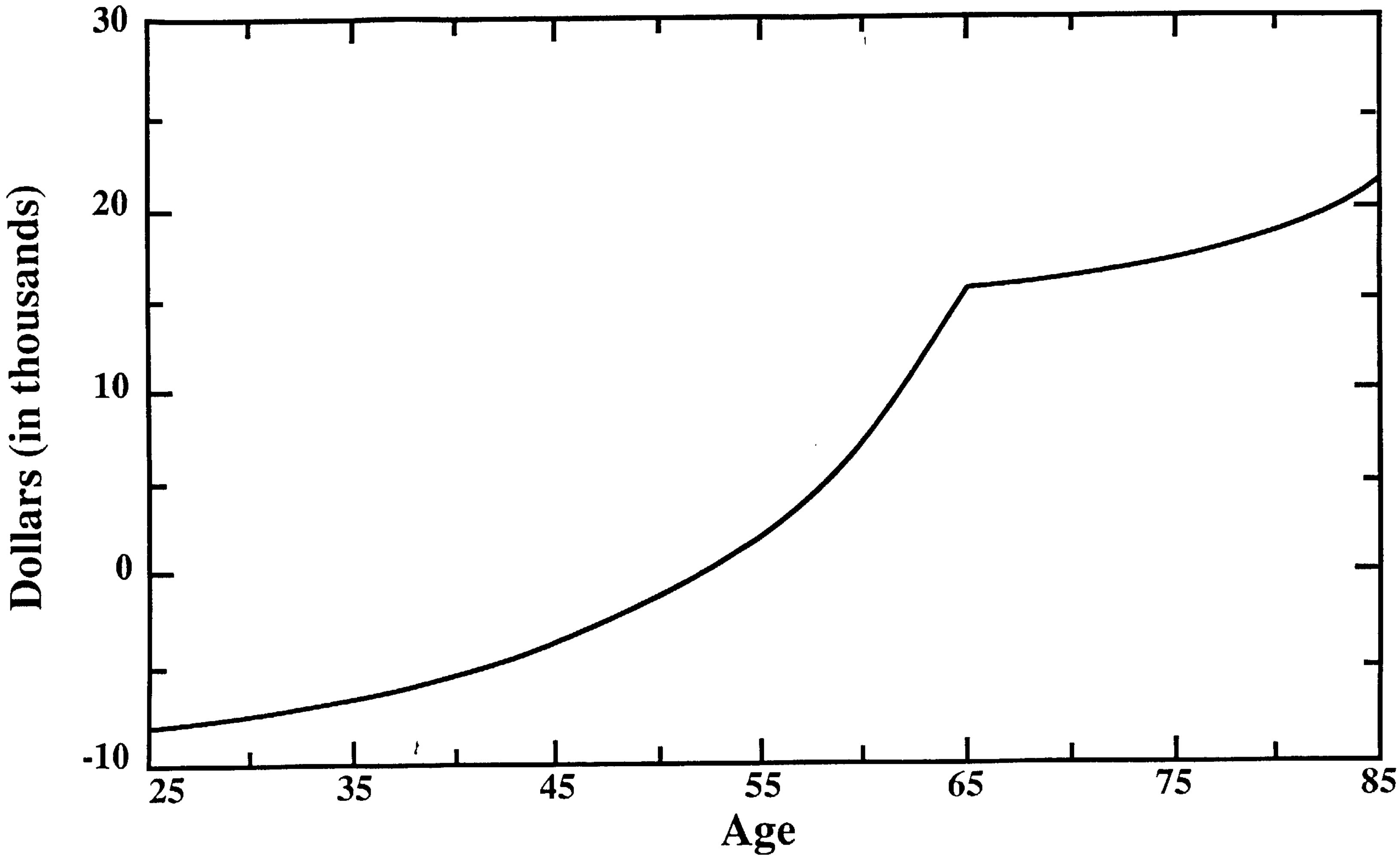


Figure 2
Present Value of Future Net Resource Use per Year of Life Saved by Averting Death by Age



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