Life-Effectiveness Analysis: A Technique for Trading Clinical Life-Years for Societal Life-Years

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Abstract

Life-effectiveness analysis is a technique that uses the relationship between family income and mortality to develop a cost-benefit procedure that trades off clinical life-years saved and societal life-years lost. In this study, life-effectiveness analysis was applied to three procedures: (1) screening women in their forties for breast cancer, (2) screening a cohort of men aged 60 to 80 years for abdominal aortic aneurysm, and (3) the prostate specific antigen test as a screen for prostate cancer for men aged 50 to 75 years. Data on mortality as a function of family income were obtained from the U.S. National Longitudinal Study, conducted by the National Institutes of Health. Age distributions came from census data, and family income distributions were obtained from federal government data. NEVADA simulation was used to calculate the number of societal life-years lost from a healthcare expenditure. The cost was distributed equally among families. The LIFESPANS algorithm was used to generate life expectancy and survival distributions. This study found that, in 1995 dollars, each $68,300 spent will result in a reduction of 1 societal life-year. Therefore, in order for a therapy to be life-effective, the cost per clinical life-year saved must be less than $68,300. Applying this method to breast cancer screening for women in their forties shows that, whereas screening saves 2,016 clinical life-years, it results in a loss of 8,917 societal life-years, for a net loss of 6,901 life-years. Prostate specific antigen test screening for prostate cancer also results in more life-years lost than gained. Screening men aged 60 to 80 years for abdominal aortic aneurysms adds more life-years than are lost. Life-effectiveness analysis reinforces the philosophy of cost-effectiveness analysis, which states that society should be willing to limit the amount that it spends to increase longevity because such spending can result in a reduction in societal longevity. By assessing the trade-off of life for life, the analytic technique of life-effectiveness eliminates the value judgment that one can trade off money and life. Thus, in this study, neither breast cancer screening for women in their forties nor prostate specific antigen screening are life-effective, because each procedure results in a net reduction of life-years. However, screening men aged 60 to 80 years for abdominal aortic aneurysms was found to be life-effective.

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Cost-effectiveness analysis is a tool for evaluating the comparative efficacy of medical tests, treatments, therapies, and other interventions.[1-17] League tables[7] rank interventions with the idea that interventions with a low cost per life-year saved should be funded prior to interventions with a higher cost per life-year saved. At some cutoff point, the cost per year of life saved becomes so high that the intervention ceases to be worth funding. Cost-benefit analysis is similar to cost-effectiveness except that an explicit dollar amount is equated to a life-year and the costs and benefits are put into the same units. The controversy over cost-effectiveness analysis centers around the argument of whether it is possible to trade human lives for money.[4-7] Although this analytic technique has been accepted to a certain degree in academia, the general public remains skeptical.

Some of this skepticism is the result of confusion about the term cost-effectiveness. Clinical cost-effectiveness is different from traditional financial cost-effectiveness, which looks purely at cash flow and uses such measures as net present value, pay-back period, and rate of return as decision criteria. Simply stated, a judgment of financial cost-effectiveness means that the chosen alternative is the cheaper of the two, whereas a judgment of clinical cost-effectiveness means that substantial health benefit is received for the money spent. The level of public skepticism might be reduced if a label of clinical cost-effectiveness for

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an intervention was understood to mean something other than the notion that the intervention will "pay for itself."

Some of the other techniques for evaluating cost-mortality trade-offs include the willingness-to-pay and human capital methods.[18-20] The human capital technique measures one's ability to produce goods for the society and employs this information as justification of the efficacy of medical intervention. Willingness-to-pay elicits direct patient preferences to determine how much an individual would be willing to spend to reduce their risk of mortality. The trade-offs involved in both of these methods are strongly dependent on either the individual's ability to pay or ability to earn money to justify medical expense. This link between an individual's earnings and whether a medical treatment is justified only heightens the public's concerns over evaluation of medical treatment.

To assist the effort of making medical treatment economic evaluation more acceptable, we introduce life-effectiveness analysis, not only as a justification of the tenets of clinical cost-effectiveness analysis, but also to minimize the confusion arising from the term cost-effective. Life-effectiveness calculates the number of nonmedical life-years lost from the reduction in societal wealth resulting from a healthcare expense; to make this determination, the technique uses the fact that mortality increases as family income decreases.[18] With this technique, we can calculate whether the number of clinical life-years saved by administering a medical treatment outweighs the societal life-years lost from the expense. We use both the data showing that mortality increases with decreasing income levels and age and income distributions to demonstrate the amount, in societal life-years, that a medical expenditure will cost. To perform the calculation, we use the LIFESPANS survival distribution and life expectancy algorithm in the software package, CONTINUOUS RISK™.

··· METHODS ···

CONTINUOUS RISK and LIFESPANS

CONTINUOUS RISK is an interpreted probabilistic programming language in which mixtures of continuous probability distributions, called "continuous trees," are used to model the variables. The functions of these independent or dependent probability distributions are calculated with Nevada simulation, a quadrature (mathematical integration) technique.

LIFESPANS is an empirical approach that calculates survival distributions and life expectancy.[23] The probability of surviving year n is equal to the product of surviving age and disease-specific causes for year n. If a disease has a nonconstant survival rate, then it is modeled with a survival table. Mathematical interpolation is used to infer values that are not listed explicitly in the table. After the survival function has been developed, it is modeled with a continuous tree. If the survival distribution is multimodal, the survival distribution is partitioned around each mode and then is modeled with a continuous probability distribution.

The Mathematical Model

We started with the fact that mortality increases with decreasing family income.[21] We used this relationship to plot a histogram of mortality as a function of family income and to fit a smooth, continuous curve to the histogram (Figure 1). Because the increase in mortality means that life expectancy decreases with decreasing wealth, we then calculated life expectancy for men as a function of family income, translated into 1995 dollars (Figure 2).

Figure 1. Mortality Multiplier as a Function of Family Income

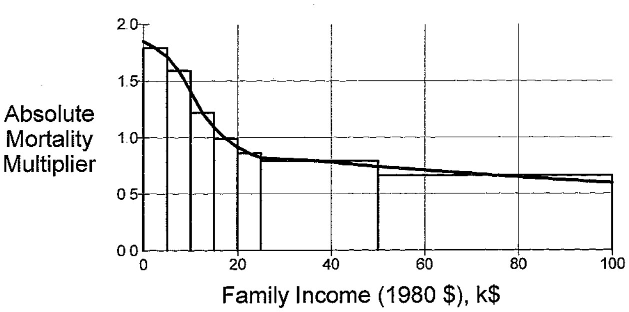


Figure 2. Male Life Expectancy versus Family Income

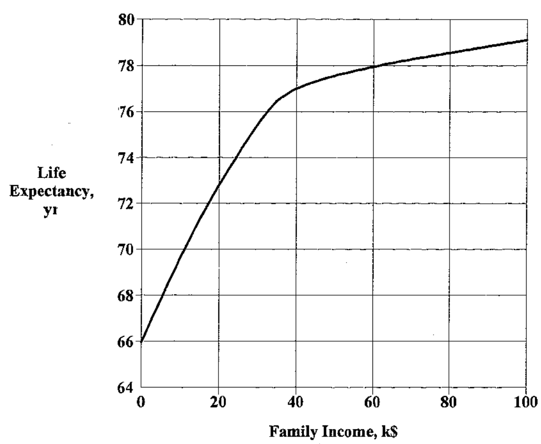


Figure 3. Probability Tree of a Societal Life-Expectancy Calculation at Current Family Income Levels

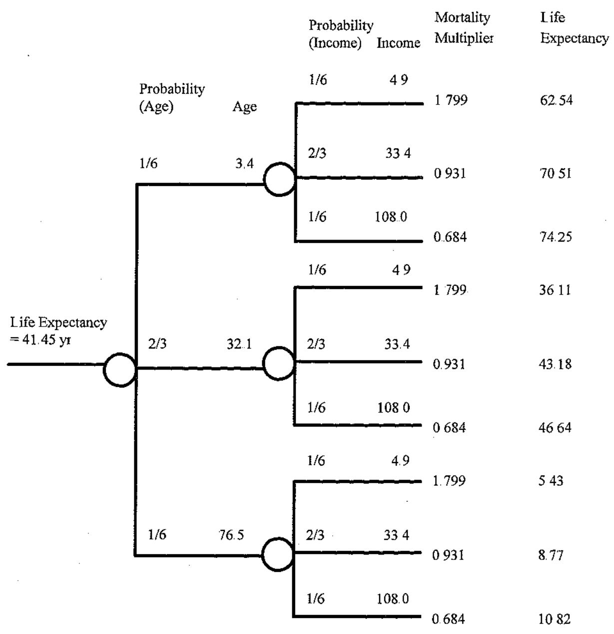
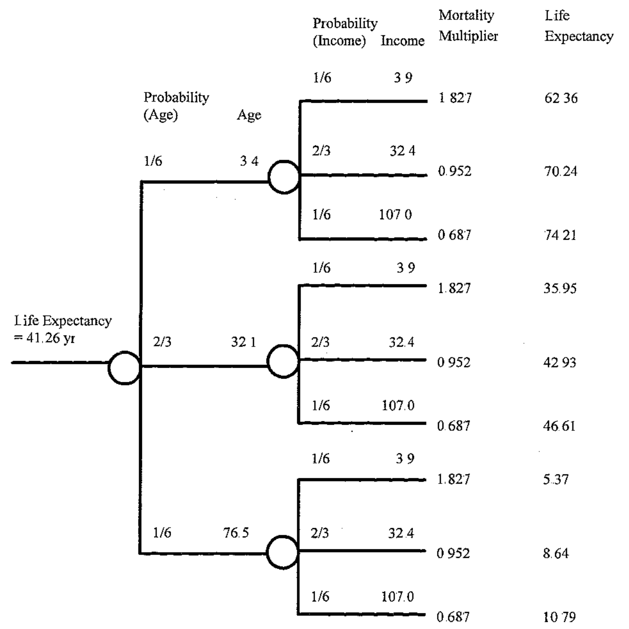


Figure 4. Probability Tree of a Societal Life-Expectancy Calculation at Family Income Reduced by $1,000/Year



Figures 3 and 4 give a probability tree illustrative of the technique to calculate societal life expectancy. For these two figures, the distribution of age and the distribution of family income was approximated with a 3-point Gauss-Hermite discrete probability distribution.[22] For each combination of age and family income, the mortality multiplier was estimated, and the life expectancy for US males was calculated using the LIFESPANS algorithm. Figure 4 repeats the exercise but reduces family income by $1,000. We see that this $1,000 annual family income reduction reduces average life-expectancy from 41.45 years to 41.26 years, a 0.19 year reduction. The analysis in this manuscript employed a larger and more accurate approximation technique, but this probability tree illustrates the method.

For the next part of the analysis, we assumed that, given the current insurance structure in the United States, a medical expenditure ultimately will be borne equally by all members of society. We consider this assumption to be valid because most Medicare, Medicaid, and insurance payments are either from tax dollars that have been raised from the entire population or from premiums collected from a large portion of the population. Thus, a medical expenditure, borne by all members of society, will have the effect of decreasing family income, increasing the mortality rate, and, ultimately, decreasing life expectancy. The analysis then sought to estimate the magnitude of this decreased life expectancy per dollar expended.

Because the mortality information was in the form of annual income data, and medical expenditures typically are a one-time cost, we used discounted cash-flow analysis to estimate the reduction in family income occurring as a result of a medical expenditure. To conduct this analysis, we amortized the medical expenditure over the life expectancy of the patients undergoing the medical treatment, at an appropriate discount rate. Current fixed-rate mortgage interest rates are good estimators for a personal discount rate, as the frame of reference for this analysis is the individual. For our analysis, we used a 9% interest rate.

To account for variations in age and income level, we integrated the life expectancy over the range of values, using a Nevada simulation. Appendix 1 shows the input and output files used in CONTINUOUS RISK to generate the results. Notice that age and income are probability distributions, and that the costs are given in thousands of dollars. The input data were run twice, once for men and once for women, and the two dollar amounts were averaged.

Screening Practices Analyzed

We applied life-effectiveness evaluation to three controversial screening practices: (1) mammography screening for all women in their forties, (2) screening a cohort of men for abdominal aortic aneurysm, and (3) prostate specific antigen (PSA) test screening of men aged 50 to 75 years for prostate cancer. We used published data on the net cost of the procedures and on the net gain in clinical life expectancy resulting from their use.

··· RESULTS ···

Adjusting for inflation to 1995 dollars and averaging costs for men and women, an expenditure of $68,300 was found to reduce societal life expectancy by 1 year. This calculated expenditure was relatively insensitive to age and gender but was sensitive to the interest rate. With a lower interest rate, of 8%, the calculated expenditure necessary to reduce societal life expectancy by 1 year increases to $76,100. With a higher, 10% interest rate, it decreases to $63,600. Discounting life expectancy substantially increased the sensitivity of the calculated expenditure sensitive to age, but not to gender. Because a discounted life expectancy was a strong function of age, but a nondiscounted life expectancy was not a strong function of age, we used a nondiscounted life expectancy in our analysis.

Breast Cancer Screening

Screening asymptomatic women in their forties for breast cancer has been the subject of controversy.[24-28] Eddy et al[24] estimated that implementing a breast cancer screening program for 25% of asymptomatic women in this age cohort would cost $406 million per year (1984 dollars), or $609 million in 1995 dollars. They further estimated that this screening program would save 2,016 life-years per year. According to life-effectiveness calculations ($609 million/$68,300), 8,917 societal life-years would be lost as a result of the ensuing reduced societal wealth, for a net loss of life of 6,901 years. If we assume that we are willing to exchange 1 clinical life-year for 1 societal life-year, then screening women in their forties for breast cancer would not be considered life-effective. The cost of the screening does not even figure into this judgment except to determine the reduction in life expectancy resulting from the financial expenditure.

Abdominal Aortic Aneurysm Screening

Screening for abdominal aortic aneurysm is another controversial subject. The following methods can be used to locate abdominal aortic aneurysms: treat emergent cases, with no screening; screen with palpation, with follow-up ultrasonography as necessary; and screen with abdominal ultrasound.

Frame et al investigated the cost-effectiveness of these methods.[29] For a cohort of 10,000 men, aged 60 to 80 years, they found that emergency surgery without screening yielded 116 incremental life-years gained, at a cost of $1.8 million. This strategy generated the additional clinical life-years at a cost of 26 societal life-years, for a net gain of 90 life-years per 10,000 men screened. Screening with palpation and ultrasonography produced 57 clinical life-years at a cost of $2.4 million dollars (35 societal life-years), for a net gain of 22 life-years. Repeat ultrasonography 5 years later resulted in 1 clinical life-year saved at a cost of $0.9 million (13 societal life-years), for a net loss of 12 life-years.

Approximately 15 million men are in the age range of 60 to 80 years. Therefore, to determine the overall net gain or loss for the population from these screening procedures, the numbers in the calculations presented here should be multiplied accordingly. On the basis of this computation, a palpation and follow-up ultrasonography screening program for 25% of men aged 60 to 80 years would save 21,375 life-years ([0.25*15 million]/[10,000*116]), but 9,750 life-years would be lost ([0.25*15 million]/[10,000*26]), for a net savings of 11,625 life-years.

Frame et al judged the first two strategies, but not repeat screening, to be marginally cost-effective. Life-effectiveness analysis reinforces their conclusions.

Prostate Cancer Screening

Numerous analyses have been performed on the expected cost and benefit of screening for prostate cancer. Optenberg and Thompson[30] showed that the first year of screening for prostate cancer would cost $27.9 billion. Dorr et al[28] and Kramer et al[29] found that screening for prostate cancer would cost approximately $12 billion for the first year. The expected annual mortality from prostate cancer therapy is 2,000 to 5,500 deaths. If screening and therapy reduce mortality by 20%, then 6,800 lives will be saved. After therapy, there is a net of 1,300 to 4,800 lives gained per year. With a 30% improvement in mortality resulting from screening and therapy, 2,000 to 5,500 lives are saved.[31]

Application of life-effectiveness analysis to prostate cancer screening shows that the expenditure of

$12 billion results in a loss to society of approximately 176,000 life-years. This number greatly exceeds the number of lives gained, as one would have to attain an average of 25 to 40 years of additional life after therapy in order for screening for prostate cancer to be life-effective. Another way to look at this trade-off is to consider that a 30% improvement in mortality increases life expectancy by 2.5 to 3.5 years. Thus, with a loss of 176,000 societal life-years, only 12,000 to 28,000 clinical life-years would be gained.

Data supporting the hypothesis that therapy for prostate cancer reduces total mortality are scarce. Therefore, in addition to the loss of societal life-years resulting from screening for and treating prostate cancer, a possible outcome of therapy could include a loss of clinical life-years.

The table summarizes the three life-effectiveness analyses presented in this study. Note that the criterion for life-effectiveness is a greater number of clinical lives saved than societal lives lost.

··· DISCUSSION ···

Efficient allocation of medical resources is becoming increasingly important in the current healthcare environment. Many practitioners in the healthcare field and the public remain skeptical of cost-benefit and cost-effectiveness analysis because of concerns that this technique relies on the equation of life with money. Life-effectiveness analysis demonstrates that allocation of medical resources is not a question of life versus money, but rather, one of life versus life. Decreasing individual and family incomes negatively affect longevity. Because most healthcare expenditures are paid out of common funds (eg, private insurance, Medicare, or Medicaid), increased utilization of resources for medical practices on the margin might increase longevity for an individual but will affect the population adversely.

Screening for rare chronic diseases is an example of a medical practice that has potential for large improvements in life expectancy for individuals who have the disease, but that provides little benefit for those without it. The many individuals who do not have the rare disease must pay for the screening procedure and for any follow-up therapy required by an abnormal screening test. This cost, then, decreases disposable income for a large majority of the population, with large benefit flowing to only a few members of that population. The purpose of life-effectiveness analysis is to provide the framework for weighing the small loss to many people and the large benefit to a few.

Prostate cancer screening and breast cancer screening in young women appear to be examples of this situation. In both cases, although lives are saved through case finding and treatment, significant financial costs are incurred by many. These costs ultimately decrease societal life expectancy by reducing overall disposable income. The net number of lives lost as a result of decreased income exceeds the number of clinical lives saved as a result of screening for and treating breast cancer in young women and prostate cancer.

Screening for abdominal aortic aneurysm in men aged 60 to 80 years does appear to be life-effective, at least with respect to the initial screening examination, because the costs per clinical life saved are much lower than for the other two procedures. The net lives lost from decreased income do not exceed the clinical lives saved through screening and treatment. Repeat screening 5 years later is not life-effective, however.

Study Limitations

This study is limited by its assumptions, the most important of which is that one is willing to trade 1 clinical life-year for 1 societal life-year. The argument against this assumption is that, although it is possible to identify the people whose clinical life-years are increased, the people whose societal life-years are lost remain anonymous. We cannot identify by name an individual who has suffered in this way as a result of an excessive medical expenditure. In litigious circles, the motivations to show causal liability are

Table. Summary of Life-Effectiveness Analyses

Screening Test	Age Range	Life-Years Gained	Annual Cost ($M)	Life-Years Lost	Net Life-Years	Life-Effective?
25% Breast Cancer Mammography	40–50	2,016	609	8,917	-6,901	No
25% Abdominal Aortic Aneurysm Ultrasonography	60–80	21,375	675	9,750	+11,625	Yes
100% PSA for Prostate Cancer	50–75	<28,000	12,000	176,000	-148,000	No

the motivations to show causal liability are stronger than those showing provision of overall benefit.

The second assumption in this study is that money is unimportant in life-effective analysis, as the only measure considered is the number of life-years gained or lost. In reality, because financial resources are expended, the dollar amounts are unlikely to be ignored. However, we are attempting to establish a framework that makes clinical evaluations acceptable to a wide audience. The ability to state that "screening for breast cancer for women in their forties is not life-effective" is more useful than the ability to state that this technique is not "cost-effective," particularly because of the extent of confusion between the concepts of financial cost-effectiveness and clinical cost-effectiveness.

The final assumption is that all medical expenditures are borne equally by members of society. It would be more correct to state that medical expenditures are borne by insured members of society and those who pay taxes. Because a loss of family income has a stronger effect on people who have lower family income than on those with higher family income, a shift of the medical expense burden to higher income levels will tend to reduce the number of life-years lost as a result of an expenditure. In fact, because a reduction in income causes a greater life reduction at low income levels than at high income levels, the number of life-years lost from an expenditure would be more than cut in half if the insurance burden were a constant *fraction* of family income, rather than a constant *rate*.

··· CONCLUSION ···

Life-effectiveness analysis demonstrates that health expenditures probably have an overall effect on both clinical life-years gained and societal life years lost due to decreased income. At an interest rate of 9% and an expenditure of $68,300, 1 clinical life-year gained equals 1 societal life-year. Therefore, life-effectiveness analysis demonstrates that screening for breast cancer in women younger than age 50 and screening for prostate cancer in men produces a net loss in life expectancy, because the gain in life-expectancy from case finding and treatment is less than the loss to society from reduced income. Initial screening for abdominal aortic aneurysms in men aged 60 to 80 years is life-effective, but repeat screening 5 years later is not.

For editorial comment, see pages 285-286

APPENDIX. CONTINUOUS RISK Input and Output File

Input Files

```
ARRAY income[10],mortmult[10];
ARRAY inc[90],life[90];
!
! Assume 30 year-old male and 9% discount rate
!

Age=30;
IntRate = .09;
!
! Fit distribution of income from almanac
!

Income87 = CDFX(.069 .184 .289 .481 .642 .815 .937 5
10 15 25 35 50 75);

!
! Fit distribution of age from almanac
!

Age90 = CDFX(.074 203 .256 .357 .532 .683 .87 .996 5
13 17 24 34 44 64 84);
!! Adjust for Consumer Price Index (cpi) in 1980 and 1987
!

CPI95 = 1.50;CPI87 = 1.17;
CPI80 = 0.85;

! Enter table of mortality as a function of 1980 income
!

income = ARRAYDATA(3 7 12 17 22 35 70);
mortmult = ARRAYDATA(1.79 1.59 1.2 .99 .86 .79 .66);

!
! Adjust to 1987 dollars
FOR (i 1 7)
{
 Income[i]=Income[i]*CPI87/CPI80
}

for(i 1 9)
{ Inc[i]=10*i-5;
!
! Use LIFESPANS algorithm to calculate life expectancy as
a function
! of income level. This example is for a male

 Life[i]=MEAN(LE(MALE,ASRMORTALITY,TABLE(In-
come,Mortmult,Inc[i]),Age));
 PRINT('income','%.0f %f\n',inc[i],life[i]);
}
!! Calculate the life expectancy effects of a $1,000 de-
crease in family income.
!
Life1 = MEAN(TABLE(Inc,Life,Income87));Life2 =
MEAN(TABLE(Inc,Life,Income87-1));
!
! Calculate the Annualized_to_Present multiplier in order
to amortize the $1,000 cost
! over the person's life expectancy.
```

```
!
Mult=ATOP(IntRate,INT(Life1));
CostFor1YearReduction = Mult/MEAN(Life1-
Life2)*(CPI95/CPI87);
end;
```

Output Files

```
VARIABLE
    PROB        MEAN   SIGMA BETA1 BETA2 BRANCH-
NAME
INCOME[1] = 4.129412
INCOME[2] = 9.635294
INCOME[3] = 16.517647
INCOME[4] = 23.400000
INCOME[5] = 30.282353
INCOME[6] = 48.176471
INCOME[7] = 96.352941
MORTMULT[1] = 1.790000
MORTMULT[2] = 1.590000
MORTMULT[3] = 1.200000
MORTMULT[4] = 0.990000
MORTMULT[5] = 0.860000
MORTMULT[6] = 0.790000
MORTMULT[7] = 0.660000
INC[1] = 5.000000
INC[2] = 15.000000
INC[3] = 25.000000
INC[4] = 35.000000
INC[5] = 45.000000
INC[6] = 55.000000
INC[7] = 65.000000
INC[8] = 75.000000
INC[9] = 85.000000
LIFE[1] = 38.247951
LIFE[2] = 41.659760
LIFE[3] = 44.938399
LIFE[4] = 46.729727
LIFE[5] = 47.130162
LIFE[6] = 47.371022
LIFE[7] = 47.863475
LIFE[8] = 48.317771
LIFE[9] = 48.730215
AGE = 30.000000
INTRATE = 0.090000
INCOME87, Expected Value = 31.424759,
 P1 = 1.000000, X1 =   31.424759  23.8889 1.41 4.65

AGE90, Expected Value = 34.360504,
 P1 = 1.000000, X1 =   34.360504  22.0803 0.05 2.13

CPI95 = 1.500000
CPI87 = 1.170000
CPI80 = 0.850000
I = 9.000000
LIFE1 = 44.117453
LIFE2 = 43.907474
MULT = 10.860505
COSTFOR1YEARREDUCTION = 66.310184
```

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