4.

A CASE STUDY: COST--EFFECTIVENESS ANALYSIS OF VACCINATION AGAINST PNEUMOCOCCAL PNEUMONIA

4.

A CASE STUDY: COST-EFFECTIVENESS ANALYSIS OF VACCINATION AGAINST PNEUMOCOCCAL PNEUMONIA

These modes of analysis [cost-effectiveness and cost-benefit] are neither good for nothing nor good for everything, and one *cannot speak of them as wholly good or bad. It is much more useful to try to specify some conditions under which they would or would not be helpful for various purposes.*

Aaron Wildavsky
University of California
1966

BACKGROUND AND INTRODUCTION

Several factors influence the use of vaccines in this country. Public demand for vaccines is influenced by individuals' perceptions regarding personal susceptibility to disease, the likelihood of local occurrence of disease, and the value of vaccination. Demand is also influenced by physicians' knowledge about vaccinations and their perceptions about patients' needs for vaccinations. (See appendix 4.1.)

Perhaps the single most important influence on vaccine availability and use is the Federal Government. For the most part, the Federal Government promotes vaccine use through its public immunization programs, which are mainly directed toward the prevention of certain childhood diseases (e.g., measles). By purchasing and distributing selected vaccines free of charge to State and local health departments, the Federal Government reduces costs and increases the availability of vaccines to consumers. (See appendix 4.2.)

Every 1 to 2 years, Congress is asked to enact legislation that authorizes the Federal Government to continue purchasing and distributing vaccines. Congress appears to base its decisions, at least in part, on the following types of judgments:

1. The appropriate use of selected vaccines, once deemed safe and efficacious by the Food and Drug Administration (FDA), will benefit society by conferring protection against certain contagious infectious diseases.
2. Many persons at high risk of contracting a disease are not being vaccinated, and this situation is detrimental to the public's health,
3. Government has the responsibility and capability of promoting the use of certain vaccines among those high risk persons who do not get vaccinated on their own.

51-329 0 - 79 - 6

In 1976 and 1978, the Federal Government established special influenza vaccination programs to promote the use of influenza vaccines intended for use by both high risk adults and children. Federally sponsored immunization programs to help prevent pneumococcal pneumonia through use of the recently licensed pneumococcal vaccine, also intended for adult use, however, have not been established. Pneumococcal vaccine has been available 11/z years, and although the Federal Government helped develop the vaccine, it has not yet actively promoted its use among individuals at high risk of contracting pneumococcal pneumonia.

Decisions regarding the extent, if any, to which the Federal Government should promote the use of pneumococcal, as well as influenza, vaccine will likely be based on criteria similar to those mentioned above. Two bodies have evaluated the new pneumococcal vaccine: the Food and Drug Administration (FDA) (see chapter 3) and the Advisory Committee on Immunization Practices (ACIP). In their deliberations, both of these bodies considered the efficacy and safety of the vaccine, the mortality produced by pneumonia and bacteremia, and the importance of certain high risk conditions. Not amassed, and hence not considered, were additional health factors such as the morbidity from pneumococcal pneumonia and medical care expenditures for vaccination or treatment.

The emphasis of this chapter is on the potential usefulness and limitations of a criterion that the Federal Government has not yet applied in allocating Federal funds for specific types of vaccinations: cost-effectiveness. Cost-effectiveness analysis (CEA) compares the costs of alternative methods of attaining a specific goal. This type of economic analysis has been used rather limitedly to help allocate health resources. (See appendix 4.3.) At least theoretically, CEA could be used to address two health policy issues: 1) the costs of using medical technologies, and 2) the relative effectiveness of using these technologies to improve health.

For illustrative purposes, OTA conducted a cost-effectiveness analysis in which it calculated the net changes in costs and effects that would result from vaccination against pneumococcal pneumonia instead of a continuing of the present situation in which pneumonia is treated if it occurs. Undertaken in light of current interest in evaluating the benefits, costs, and cost-effectiveness of new medical technologies, OTA's analysis of vaccination against pneumococcal pneumonia represents a case study of the cost-effectiveness technique.

In OTA's cost-effectiveness analysis presented below, the costs and health effects of pneumococcal vaccine, a new preventive technology, are evaluated from a societal perspective, as well as from the perspective of Medicare. Specifically addressed is whether expenditures on vaccination to help prevent pneumococcal pneumonia are a more efficient use of resources than expenditures on treatment for pneumococcal pneumonia in different subgroups of the population.

Findings from OTA's analysis and issues related to the potential utility of CEA to Federal health policymakers are presented in chapter 6. Federal options related to these issues appear in chapter 7.

MEASUREMENT OF HEALTH EFFECTS AND SOCIETAL MEDICAL COSTS OF PNEUMOCOCCAL VACCINATION

In this cost-effectiveness analysis, expected changes in health effects and medical care costs that would result from vaccination against pneumococcal pneumonia rather

than continuing reliance solely on treatment are measured. The analysis is limited to events within the medical care sector, but includes all health and cost effects within this sector. Costs incorporate both medical care expenditures and savings. Effects consist of changes in years of healthy life. The cost-effectiveness ratio represents the net societal medical cost per year of healthy life that would be gained by a vaccinated person. That ratio indicates the net change over continuation of the present situation if a person were vaccinated.

The analysis takes into account the effect of the pneumococcal vaccine only on pneumococcal pneumonia. Excluded is any possible immunity conferred by the vaccine against other pneumococcal diseases, such as pneumococcal otitis media (middle ear infection) or pneumococcal meningitis (infection in the membranes surrounding the brain and spinal cord). The efficacy of the vaccine against pneumococcal diseases other than pneumonia has not yet been assessed in clinical trials. Because of these exclusions, the cost-effectiveness ratios derived in this analysis may be conservative relative to the overall cost-effectiveness of the vaccine against all pneumococcal diseases. Furthermore, the assumption is made that pneumococcal vaccination of some individuals in the population will not produce herd immunity among the unvaccinated.

Cost-effectiveness ratios were based on a single hypothetical vaccination program conducted in June 1978. A simulation model was used to estimate the costs and effects that would result from 1978 through 2050 for two closed populations, one vaccinated and the other unvaccinated. Past rates of medical expenditures, days of illness, and mortality formed the basis of projections. (See appendixes 4.4, 4.5, and 4.6.)

Health Effects

In the analysis, the health effects of pneumococcal vaccination are expressed in quality-adjusted life years (QALYs). [1] QALYs incorporate into a single index changes in both mortality and morbidity, thus allowing comparisons between programs that mainly reduce death and those that mainly reduce illness or disability. This index allows measurement of the effects of health care interventions without attaching a monetary value to increases or decreases in days of health or years of life.

To construct QALYs, different disability states are assigned rankings in terms of their relationship to the extremes of full functioning, on the one hand, and death, on the other. For example, on a scale where a year of full functioning is 1 and a year of death is O, a year with a minor health problem might rank as .9, and a year with a major health problem might rank as only .2. QALY rankings of different degrees of health can be thought of as representing tradeoffs between more years of unhealthy life and fewer years of healthy life. (For further details on QALYs, see appendix 4.4.)

For purposes of this CEA, degrees of health were divided into four categories: death, disabilities with confinement to bed, disabilities without confinement to bed, and full functioning. Weighings for these different states were drawn from an analysis by Bush, Chen, and Patrick of a phenylketonuria (PKU) screening program: O for a year of death, .4 for a year of bed disability, .6 for a year of nonbed disability, and 1.0 for a year of full functioning (Bush, 1973). [2] The sensitivity of the results to these weights is tested in the course of the analysis.

This scale of weights was applied to years of life at whatever age changes in health status might be expected to occur. Thus, a year of health or life gained by a 5-year-old

[1] The term "quality-adjusted life years" was coined by Zeckhauser and Shepard, although other health analysts have used the concept. (See Zeckhauser, 1976.)

[2] These weights were derived by averaging values from the Bush, Chen, and Patrick survey. (See Bush, 1973.)

was weighted the same as a year gained by a 65-year-old. This simplifying assumption was made despite the fact that individuals and society may well value years of extra health or life differently depending on the age at which the additional years occur.

Medical Care Costs

Costs measured in the analysis, expressed in dollars, reflect changes in societal medical care expenditures that would result from pneumococcal vaccination. Included as costs are increases or decreases in the medical expenditures incurred by all payers—patients, private third-party payers, and governments. According to OTA's analysis, total treatment costs for pneumococcal pneumonia in the United States in *1978* were an estimated $135 million. (See table 11.)

Table 11 .—Estimated Expenditures by Age Group for the Treatment of Pneumococcal Pneumonia in the United States (1978)

Age group	Estimated expenditures				
	Ambulatory care	+	Hospital costs	=	Total
2-4 years	$ 3,234,000	+	$ 8,851,000	=	$ 12,085,000
5-24 years	2,192,000	+	6,181,000	=	8,373,000
25-44 years	3,125,000	+	14,430,000	=	17,555,000
45-64 years	2,573,000	+	31,940,000	=	34,513,000
65+ years	1,733,000	+	61,560,000	=	63,293,000
Total	$12,857,000	+	$122,962,000	=	$135,819,000

SOURCE OTA.derived estimates based on data prowded by sources identified In appendix=4

Changes in costs outside of the medical care sector are excluded from the analysis. Changes in years of healthy life, in particular, may influence other sectors as changes in working days and productivity; similarly, any changes in resources used in the provision of medical care might have implications for production and expenditures on other goods and services. In benefit-cost analysis (BCA), such systemwide effects are included and expressed in dollar terms. In this cost-effectiveness analysis, systemwide ramifications are to some extent implicit in changes in QALYs. Increases or decreases in years of healthy life implicitly carry implications for economic effects, as well as for personal and social effects (e.g., changes in family life and in the age distribution of the population).

Costs in this CEA are expressed in 1978 dollars. Thus, it is tacitly assumed that future inflation will occur at the same rate in the medical care sector as in the general economy. In fact, medical prices in recent years have been rising more rapidly than the Consumer Price Index (CPI). It is unclear, however, what portion of higher medical prices is attributable to higher prices for the same services (inflation) and what portion to new or different services (changing quality and intensity). Furthermore, predicting relative price rises in different medical services, such as physician fees, hospital days, and drug-prices would be difficult.

COST-EFFECTIVENESS EQUATION AND MODEL

Cost-effectiveness ratios (C/E) for pneumococcal vaccination, expressing the net medical expenditure per year of healthy life gained by a vaccinated individual, were computed with the basic formula that appears below:[3]

[3]The formula used in this analysis is similiarto the formula used by Weinstein and Stason in their analysis of a hypertension treatment program. One difference is that the term E_i has been added to account for illnesses in extended years of life. (See Weinstein, **1976.)**

$$C/E = (C_p - C_t + C_{se} + C_i) / (E_{ly} + E_m - E_{se} - E_i) = \text{Net costs/Net effects}$$

where:

C_p = Cost of preventive vaccination
C_t = Cost of treating pneumococcal pneumonia prevented by vaccination
C_{se} = Cost of treating vaccine side effects
C_i = Cost of treating future illnesses not prevented by vaccination among vaccinees whose lives are prolonged as a result of vaccination
E_{ly} = Life years gained from vaccination
E_m = QALYs of morbidity prevented by vaccination
E_{se} = QALYs of morbidity and mortality associated with vaccine side effects
E_i = QALYs of morbidity from future illnesses not prevented by vaccination among vaccinees whose lives are prolonged as a result of vaccination

Separate cost-effectiveness ratios were calculated for vaccinating people in each of five different age groups: 2 to 4 years, 5 to 24 years, 25 to 44 years, 45 to 64 years, and 65 years and older. Research has not proved pneumococcal vaccine to be efficacious for children under the age of 2 (Ammann, 1977); consequently, this age group was eliminated from the analysis. The choice of the other age categories was based on variation in pneumonia incidence and divisions in available data sources.

No separate cost-effectiveness ratios were calculated for males and females or for different racial groups. When sex-specific data were available and reliable, though, these were used in the calculations. The only high risk group for which a separate cost-effectiveness ratio was calculated on the basis of empirical data was that comprised of people 65 years and older. Without question, however, ratios for other high risk groups would be important to calculate. Hypothetical cost-effectiveness ratios, based solely on assumptions, were also calculated for high risk groups.

BASE CASE AND SENSITIVITY ANALYSIS

Cost-effectiveness ratios generated in this analysis depend on assumptions about the value of several variables. The magnitude of the reduction in the incidence of pneumococcal pneumonia, for example, depends on assumptions about the duration of vaccine immunity, the efficacy of the 14-valent vaccine, and the percentage of pneumococcal pneumonia caused by the polysaccharide types in the vaccine. The calculations also depend on whether the vaccination program is assumed to be administered through the public or the private sector, which affects the cost of vaccination, and on whether serious adverse reactions, such as Guillain-Barre Syndrome (GBS), are expected to be associated with use of the vaccine.

As none of these variables or factors was certain, a base case was established in which the most likely value was assigned to each variable. Decisions regarding the assignment of values in the base case were made on the basis of such factors as the preponderance of findings from the clinical literature. (See appendixes 4.4, 4.5, and 5.1.)

For purposes of the base case analysis, the following assumptions were made:

- QALY weights of .4 for bed disability and .6 for nonbed disability on a scale of O for death and 1 for full functioning;

- Discount rate of 5 percent applied to costs and effects occurring after 1978;
- Private sector vaccine provision at a cost of $11.37 per vaccination;[4]
- 15 percent of all pneumonia as pneumococcal (Bentley, 1979; Austrian, 1979; Filice, 1979; Fraser, 1979);
- 75 percent of pneumococcal pneumonia caused by the 14 types of pneumococci against which the vaccine is effective (Austrian, May 1, 1976; Austrian, et al., 1976; Fey, 1975; Valenti, 1978);
- 80-percent rate of vaccine effectiveness against the 14 types of pneumococci represented in the vaccine (Austrian, et al., 1976; Smit, 1977);
- Vaccine side effects of one case per 100,000 persons vaccinated of severe systemic reaction and five cases per 100 of fever;[5]
- An average of 8 years' immunity provided by the vaccine (Heidelberger, 1953);
- Rate of 1978 pneumonia deaths based on death certificates with pneumonia specified as the underlying cause of death (U.S. Ex. Br., NCHS, DVS);
- Same projected rate of decline for pneumonia deaths over time as for all deaths;[6]
- Rate of 1978 age-specific hospital cases of pneumonia in which pneumonia was the first-listed diagnosis (U.S. Ex. Br., NCHS, HDS); and
- Rate of 1978 age-specific ambulatory visits for Pneumonia from the National Ambulatory Medkal "Care Survey (NAMCS), a survey of physicians (U.S. Ex. Br., NCHS, NAMCS).

The influence of selecting different values for each of these 12 variables was tested in a sensitivity analysis. For further discussion of the values assigned to variables in the base case and sensitivity analysis, see appendix 4.4.

DATA SOURCES

For **many estimates** used in OTA's analysis, data were collected from several sources and many assumptions had to be made. No reliable estimate of the incidence of pneumococcal pneumonia, for example, is available; in the analysis, two assumptions were used. One was that the percent of pneumonia caused by pneumococci is uniform throughout all age groups. Although age-specific incidence rates for pneumococcal pneumonia may indeed vary, no study has provided data on which to base empirically derived rates. The second assumption was that the severity of a case of pneumococcal pneumonia is equivalent to the severity of **an** average case of pneumonia.

Data on the incidence of pneumonia and the costs of pneumonia treatment were combined from several sources: the National Center for Health Statistics (NCHS), including the Division of Vital Statistics (DVS), the Health Interview Survey (HIS), the Hospital Discharge Survey (HDS), and the National Ambulatory Medical Care Survey (NAMCS); Blue Cross; and the HEW Medicare program. An estimate of pneumonia's ef-

---

[4]This cost estimate was based on a product cost of $4.90 for a dose of the vaccine (Beck, 1978) and an injection fee of $6.47 (Schieber, 1976; CMA, 1969; U.S. Ex. Br., BLS, 1978).

[5]This estimate was based in part on data reported in premarketing clinical investigations (see ch. 3) and in part on adverse reaction case reports voluntarily submitted by physicians to Merck Sharp and Dohme, BOB, and CDC (Broome, 1978). The incidence of reported adverse reactions changes continually, and this estimate does not incorporate data generated since September 1978.

[6]This assumption was consistent with the observation that pneumonia mortality has declined at a faster rate among the young than among the elderly and avoids the mortality rates' rapidly reaching zero.

feet on individuals' health was based on data regarding the number of pneumonia deaths from NCHS's Division of Vital Statistics and the number of pneumonia illness days from HIS. HDS provided data on the number and length of hospitalizations for the treatment of pneumonia; HIS provided data on the number of hospital outpatient visits. The number of physician office visits for pneumonia came from NAMCS and HIS.

The estimate that 15 percent of all cases of pneumonia are caused by pneumococci was based primarily on an informally derived consensus among selected researchers, as well as data generated in a small study of hospitalized patients in Rochester, N.Y. **(Bentley, 1979). The range** of values used for this variable in the sensitivity analysis was derived from studies reported in the clinical literature.

To obtain estimates of the costs of treating pneumococcal pneumonia, the information regarding the utilization of pneumonia treatment facilities was matched with other data concerning the cost of treatment at each type of medical facility. Estimates of costs per inpatient day were based on costs for hospitalized pneumonia cases covered by Blue Cross under the Federal Employees Health Benefit Program (Blue Cross, 1978). Hospital outpatient costs, office visit costs, and physicians' fees were estimated on the basis of charges for physician services, lab tests, and X-rays under Medicare (Schieber, 1976), and on general charges for drugs.

For several variables in the cost-effectiveness equations, different data sets provided conflicting estimates. In such cases, the most probable value was used as the base case estimate, and alternative values were used in the sensitivity analysis. In the base case, for example, the number of pneumonia deaths (used to calculate the pneumonia mortality rate) was drawn from death certificates on which pneumonia was listed as the underlying cause of death. In the sensitivity analysis, the estimate of pneumonia mortality depends on the number of death certificates on which pneumonia was mentioned as a contributing cause of death. Similarly, in the base case, the number of inpatient pneumonia cases was based on the number of cases discharged from hospitals with pneumonia listed as the first diagnosis. Because pneumonia might have been an important factor leading to hospitalization, even in cases where it was not listed first, the number of hospital discharges with any diagnosis that listed pneumonia was used in the sensitivity analysis.

The number of pneumonia-related physician office visits reported in NAMCS was about one-half that reported in HIS. In the base case, OTA used data from NAMCS, because this survey is based on physicians' reporting of pneumonia, Physician reporting was believed to be more accurate than the HIS method of reporting, which is based on interviews of the noninstitutionalized population, who might report other respiratory diseases as pneumonia. Other HIS estimates, including hospital outpatient visits and pneumonia illness days, were halved in the base case. Although crude, this adjustment reflects the same degree of patient overreporting in HIS as was assumed for office visits. The importance of this assumption was tested in the sensitivity analysis.

Other data sources and studies used to derive estimates for pneumococcal pneumonia vaccine's cost-effectiveness are discussed in appendixes 4.4 and 4.5.

RESULTS

The results of the base case and sensitivity analysis for pneumococcal vaccination illustrate the types of information that a CEA can convey. The presentation of the results of OTA's analysis below constitutes neither advocacy of, nor opposition to, pneumococcal vaccination to help prevent pneumonia.

Most of the results are presented as "per vaccinee." Costs and effects per vaccinee are not affected by the number of people vaccinated. This relationship reflects assumptions made in the analysis that the price of vaccination is not changed by the number of people vaccinated and that people who are not vaccinated derive no herd immunity from others' vaccinations.

Base Case

Cost-effectiveness ratios for pneumococcal vaccination, derived using base case assumptions, are presented in table 12. With base case assumptions, pneumococcal vaccination against pneumonia would result in a net improvement in health (QALYs), but no savings in expenditures for any age group. Vaccination would be most cost-effective for those **65** years and older—about $1,000 per QALY gained.

Cost-effectiveness ratios for vaccination, expressing net societal medical cost per QALY gained, improve with increasing age of the vaccinee at the time of vaccination. Net medical cost per QALY gained for a vaccinee aged 2 to 4 is about $77,000. This cost drops to $55,000 for ages 5 to 24,$23,000 for ages 25 to 44,$6,000 for ages 45 to 64, and $1,000 for **ages 65 and older. As age at** the time of vaccination increases, net medical costs decline and the gain in QALYs increases. Per vaccinee net costs range from about $10 for ages 2 to 4 to about $7 for ages **45 to 64;** QALYs range from .00013 (.05 days) for ages 2 to 4, to .00118 (.43 days) for ages 45 to 64; for older ages, the gain in QALYs remains positive, but small. (See table 12.)

For all ages combined, the overall cost-effectiveness ratio per vaccinee is about $4800 per **QALY gained. This Overall ratio** illustrates by contrast the difference in the cost-effectiveness of a vaccination program that can be achieved by targeting vaccinations to specific subgroups of the population, namely, the higher cost-effectiveness of vaccinating the elderly ($1,000 per QALY) and the lower cost-effectiveness of vaccinating the very young ($77,000 per QALY).

Even when a program is not actually cost-saving, it may be deemed cost-effective. The majority of people would be willing to pay something to gain a year of healthy life, and a consensus exists that most people would willingly spend several hundred dollars

Table 12.–Per Vaccinee Cost-Effectiveness of Pneumococcai Vaccination (Base Case Results)

Per vaccinee costs and effects of vaccination	Age group					
	2-4 years	5-24 years	25-44 years	45-64 years	65+ years	All ages
Net cost[a], ...	**$10.30**	**$10.20**	**$9.70**	**$6.80**	**$4.40**	— [b]
Net effect (QALYs)[c]. . . .	.00013	.00018	.00042	.00118	.00435	—b
Cost-effectiveness ratio[d]	$77,200 / **QALY**	$55,3001 **QALY**	$22,9001 **QALY**	$5,7001 **QALY**	$1,000 / **QALY**	**$4,8001 QALY**

[a]Net cost equals the total of:
C_p = Cost of preventive vaccination
C_t = Cost of treating pneumococcal pneumonia prevented by vaccination
C_{se} = Cost of treating vaccine side effects
C_i = Cost of treating illnesses not prevented by vaccination in extended years of life
[b]Net per vaccinee costs and net per vaccinee effects for all ages combined were not calculated.
[c]Net effect (QALYs) equals the total of:
E_{ly} = Life years gained from vaccination
E_m = QALYs of morbidity prevented by vaccination
E_{se} = QALYs of morbidity and mortality associated with vaccine side effects
E_i = QALYs of morbidity from illnesses not prevented by vaccination in extended years of life
QALY = Quality-adjusted life year
[d]The age-specific cost-effectiveness ratios that are shown, expressing the net societal cost per QALY gained by vaccinated individual, were calculated on the basis of more exact numbers for net costs and effects than those that appear in this table.

for each healthy year gained (Weinstein, 1976). In terms of their economic efficiency, alternative programs or interventions with low cost-effective ratios might be more easily justified that those with high ratios (e.g., those costing over $50,000 per *QALV (Wein-*stein, 1976).

Net costs and effects of pneumococcal vaccination for the total population are shown in table 13. These numbers were calculated for illustrative purposes only. Total population costs and effects of vaccination would depend on the number of people vaccinated, which in turn might depend on such factors as the perceived threat of disease, cost of vaccine, and type of vaccine program. (See appendix 4.1.) Pneumococcal vaccination rates are difficult to predict. Most vaccines are intended primarily for children, not adults, and age-specific vaccination rates are cumulative over many years. The vaccination rates used to calculate the numbers in table 13 were the age-specific influenza vaccination rates in 197s, a nonepidemic year prior to the swine flu episode. Influenza vaccine, like pneumococcal vaccine, is targeted to high-risk adults and children, but generally confers protection for a single year or until the antigenic components of the influenza virus shift. As was assumed in base case for pneumococcal vaccinations, influenza vaccinations in 1975 were administered through the private sector.

Table 13.—illustrative Population Costs and Effects of Pneumococcal Vaccination

Population costs and effects of vaccination	Age group					
	2-4 years	5-24 years	25-44 years	45-64 years	65+ years	All ages
Net cost[b](in $1,000)	$23,500	$24,300	$42,700	$36,700	$22,600	**$150,000**
Net effect[c](QALYs).	300	440	1,870	6,400	22,400	31,400
Cost-effectiveness ratio[d].	$77,200/ QALY	$55,300/ QALY	$22,900/ QALY	$5,7001 QALY	$1,000/ QALY	$4,8001 QALY

[a]The numbers in this table were calculated for illustrative purposes only. The demand for pneumococcal vaccine cannot be predicted with any degree of certainty, so it was assumed that the percentages of people who would be vaccinated with pneumococcal vaccine would approximate the age-specific percentages of people who were vaccinated with influenza vaccine in 1975. Costs were calculated on the assumption that there would be no economies of scale; effects, on the assumption that there would be no herd immunity.

[b]Net cost equals the total of:
C_p = Cost of preventive vaccination
C_t = Cost of treating pneumococcal pneumonia prevented by vaccination
C_{se} = Cost of treating vaccine side effects
C_i = Cost of treating illnesses not prevented by vaccination in extended years of life

[c]Net effect (QALYs) equals the total of:
E_{ly} = Life years gained from vaccination
E_m = QALYs of morbidity prevented by vaccination
E_{se} = QALYs of morbidity and mortality associated with vaccine side effects
E_i = QALYs of morbidity from illnesses not prevented by vaccination in extended years of life
QALY = Quality-adjusted life year

[d]The age-specific cost-effectiveness ratios that are shown, expressing the net societal cost per QALY gained by vaccinated individual, were calculated on the basis of more exact numbers for net costs and effects than those that appear in this table.

The numbers in table 13 demonstrate the degree to which per vaccinee costs and effects of a pneumococcal vaccination program are magnified when considered for the population as a whole. Vaccinating 21.5 percent of the population age 65 and over, for example, could cost about $23 million and yield about 22,000 QALYs over the vaccinees' lifetimes. Vaccinating all age groups might have a net cost to the health system of about $150 million and would add about 31,000 QALYs.

Sensitivity Analysis

The importance of certain variables in the cost-effectiveness model is suggested by the results of the sensitivity analysis in table 14. Especially for people in younger age groups, cost-effectiveness ratios change markedly as values for particular variables are

Table 14.—Per Vaccinee Cost"Effectiveness of Pneumococcal Vaccination (Sensitivity Analysis Results)

Variable	Assigned values[a]	Per vaccinee cost per QALY by age group[a] 2-4 years	5-24 years	25-44 years	45-64 years	65+ years	All ages
QALY weightings for bed- and nonbed-disability days	Bed-day $\sqrt{.4}$ Nonbed-day $\sqrt{.6}$	$80,700	$58,400	$24,000	$6,600	$1,200	$5,500
	*Bed-day $\sqrt{.4}$ Nonbed-day $\sqrt{.6}$	*$77,200*	*$55,300*	*$2,900*	*$5,700*	*$1,000*	*$4,800*
	Bed-day $\sqrt{.4^2}$ Nonbed-day $\sqrt{.6^2}$	$76,000	$53,700	$22,000	$5,000	$900	$4,200
Discount rate applied to costs and effects occurring after 1978	No discount rate	$21,700	$17,100	$9,000	$2,700	$700	$2,700
	*5 percent	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	10 percent	$181,800	$127,700	$46,500	$10,600	$1,600	$7,700
Cost of vaccination	$3.45	$17,900	$12,300	$4,200	**	**	**
	*$11.37	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
Percent of pneumonia that is pneumococcal	10 percent	$150,000	$101,300	$38,800	$10,800	$2,300	$8,500
	*15 percent	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	35 percent	$23,100	$17,100	$7,000	$200	**	$700
Percent of pneumococcal pneumonia caused by types of pneumococci represented in the vaccine	50 percent	$150,800	$101,300	$38,800	$10,800	$2,300	$8,500
	*75 percent	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	100 percent	$50,700	$37,100	$15,600	$3,300	$400	$3,000
Pneumococcal vaccine's rate of efficacy against type-specific pneumococcal pneumonia	40 percent	$275,800	$166,700	$57,200	$16,100	$3,700	$12,300
	*80 percent	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	100 percent	$55,600	$40,600	$17,100	$3,800	$500	$3,300
Incidence of GBS as a vaccine side effect	*No GBS	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	Same as with swine flu vaccine	$77,200	$57,800	$23,800	$5,900	$1,000	$4,900
Duration of immunity conferred by the vaccine	3 years	$393,800	$262,000	$82,100	$22,170	$4,067	$14,800
	*8 years	*$77,200*	*$55,300*	*$2,900*	*$5,700*	*$1,000*	*$4,800*
	72 years	$7,100	$3,300	$1,000	$400	$300	$500
Number of pneumonia deaths, 1978	Pneumonia mentioned on death certificate[b]	$19,700	$12,900	$6,200	$2,000	$1,000	$1,900
	*Pneumonia listed as underlying cause of death on death certificate	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
Projected decline in the pneumonia death rate, 1978-2050	Fast decline[c]	$113,500	$84,400	$35,200	$8,200	$100	$6,700
	*Same decline as the overall death rate	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	No decline	$76,800	$55,000	$22,500	$5,700	$1,000	$4,800
Number of hospitalized pneumonia cases	*Pneumonia first-listed diagnosis on hospital discharge summary	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*
	Pneumonia any-listed diagnosis on hospital discharge summary	$75,000	$53,100	***$20,900***	***$2,800***	• *	$2,700
Number of ambulatory pneumonia cases and number of pneumonia morbidity days	Higher estimates based on HIS data	$51,000	$40,700	$19,400	$5,200	$1,000	$4,400
	*Lower estimates based on NAMCS data and adjusted HIS data	*$77,200*	*$55,300*	*$22,900*	*$5,700*	*$1,000*	*$4,800*

*Base case values

**In these instances, vaccination resulted in negative costs—or savings. Such savings are not displayed, however, because they can be misleading. Actual per vaccinee effects and savings are quite small. For example, a typical per person saving is less than $5, and a per person net QALY gained is around 1 to 2 days.

[a]For information regarding the sources of the values used to generate cost-effectiveness ratios appearing in this table, see appendix 4.6. For a description of the manner in which values were selected for the base case and sensitivity analysis, see appendix 4.4. Actual calculated values were rounded off to the nearest $100.

[b]The last year data on pneumonia mentions were available was 1969. Death rates based on pneumonia mentions were calculated with 1969 data. Other data used in this study are from more recent years.

[c]Fast decline implies that 97 percent of pneumonia deaths could be eliminated within 40 years.

changed. In the sensitivity analysis, selected values were altered one at a time; the variables that were not being tested were assigned their base case values.

One critical variable in terms of its impact on the results is the average *duration of the immunity* conferred by pneumococcal vaccine. Studies have shown that vaccinated individuals maintain serum antibody levels, and thus may be protected against pneumococcal pneumonia, for at least **3** to *8* years (Heidelberger, 1953). Some scientists, however, believe that the immunity may last a lifetime (Robbins, 1978; Hill, 1978). The assumption made in the base case analysis was that the average duration of immunity is **8** years. If immunity extends beyond **8** years to lifetime protection, the cost-effectiveness of vaccination improves dramatically. For all ages combined, the overall cost of adding a QALY is reduced from **$4,800** to **$500** when the duration of immunity increases from **8** years to lifetime **(72** years). By contrast, if immunity lasts only **3** years, then the overall cost of adding a QALY increases to $14,800.

Altering the *discount rate* for costs and effects occurring after **1978** alters the results substantially as well. Using a 10-percent discount rate, instead of the 5-percent rate used in the base case, decreases the cost-effectiveness of vaccination for people from 2 and 64 years. The ratio for all ages is $4,800 per QALY gained with a 5-percent discount rate and $7,700 per QALY gained with a 10-percent rate. While the initial expense of vaccination itself occurs in 1978, most of the benefits from vaccination (i. e., reduced pneumonia treatment costs and improved health) appear in subsequent years. Thus, for those between **2** and 64 years, raising the discount rate reduces the relative level of future benefits to present costs. This effect is not so pronounced for people 65 years and older, however, because for the elderly, initial vaccination costs are soon offset by savings in pneumococcal pneumonia treatment costs. Applying a higher discount rate to effects, most of which occur in subsequent years, does decrease the gain in QALYs for people in this age group. When no discount rate is used, cost-effectiveness ratios for people of all ages improve.

Another influential variable is the initial cost of *vaccination.* The cost per dose used in the base case was $11.37, the estimated cost under private provision. Using a lower cost of $3.45,[7] the estimated cost under a public immunization program, improves the cost-effectiveness of vaccination for every age group. Pneumococcal vaccination then yields cost savings for those 45 years and older, and costs from $4,000 to $18,000 per QALY gained for those 2 to 44 years old.

As one would expect, selection of larger values for variables relating to pneumonia morbidity and treatment costs, such as *days of disability, days of hospitalization,* and *number of ambulatory visits,* improves the cost-effectiveness of vaccination.

Changing the projected *rate of decline in the pneumonia death* rate produced some unexpected results. It was expected that a faster decline would reduce the vaccine's benefits and make it less cost-effective. That result held for people aged **2** to 64, but for people **65** years and older, a faster decline improves the cost-effectiveness of vaccination. It is possible that the reduction in pneumonia treatment costs resulting from vaccination would more **than** offset increased costs and morbidity from nonpneumonia illnesses and the lesser gain in life expectancy from vaccination. With a faster decline in age-specific pneumonia death rates, cost-effectiveness ratios are less favorable for those **2** to 64 years old.

Creating a hypothetical probability of contracting a severe, rare vaccine side effect, such as *Guillain-Barre Syndrome (GBS),* produces little or no change in cost-effectiveness

[7]This figure is based on the assumption that the cost of vaccination under a public immunization program would be $1.00 (Hinman, 1978) and that the product cost of one dose of the vaccine would be $2.45 (Beck, 1978; Chin, 1978).

ratios. Treatment and disability costs associated with a case of GBS were estimated (Asbury, 1978). Even in the extreme case in which the age-specific incidence of GBS are assumed to equal those associated with swine flu vaccination, cost-effectiveness ratios for all ages remain substantially unchanged from the base case. (See discussion of GBS in appendix 5.1.)

The results show little sensitivity to different *QALY weightings* for bed- and nonbed-disability days. The lack of sensitivity to these weighings indicates that the health effects of pneumococcal vaccination arise more from postponing death than from reducing disability caused by pneumococcal pneumonia.

As expected, a higher *percentage of pneumonia that is pneumococcal,* a higher *percentage of pneumococcal pneumonia caused by vaccine types,* or greater vaccine *efficacy* against these types improves the cost-effectiveness of vaccination for all age groups. Values for these variables representing the higher boundary of the reasonable range produce cost-effectiveness ratios that are favorable not only for people 65 years and over, but for those between 45 and 64, as well.

MODIFICATION OF THE MODEL FOR THE HIGH RISK POPULATION

If data had been available, this cost-effectiveness analysis would have been performed, not only for individuals in different age groups, but also for individuals (other than elderly) at high risk for pneumococcal pneumonia. Individuals at high risk are both more susceptible to contracting pneumococcal pneumonia and more likely to suffer serious consequences from the disease. In two studies, persons with the following medical conditions were found to be at a higher risk of dying from bacteremic pneumococcal pneumonia than were those without these conditions: chronic lung disease, chronic heart disease, chronic renal failure, and diabetes mellitus or other metabolic disorders (Austrian, 1964; Mufson, 1974). As a result of these findings, the official labeling for this vaccine includes recommendations for its use particularly in people with these medical problems.

Data on the number of individuals in the population with one or more of these high risk conditions, unfortunately, are not available. Furthermore, because data are unavailable, the extent of pneumococcal pneumonia and other diseases within these groups cannot be determined. More specifically, the degree to which the types of pneumococci represented in the vaccine cause pneumonia among high risk groups is not known.

To demonstrate the importance of developing a cost-effectiveness analysis for high risk individuals, therefore, OTA designed a purely illustrative model. The high risk model was based mainly on variations of data used in the base case analysis. [a] For most of the variables used in the analysis, the assumption was arbitrarily made that the value of the variable for high risk individuals would be approximately twice the value of the variable for an "average" individual. Thus, it was assumed that the cost of medical care in extended years of life for high risk individuals would be two times greater than the cost

[a] In some cases, other data sources were used. For example, the numbers of persons at high risk in each age group were based on crude estimates derived by Joel Kavet on the percentage of the general population within different age groups with selected cardiovascular diseases, bronchopulmonary diseases, renal diseases, and metabolic diseases. (See Kavet, 1972.) For the number of pneumonia hospitalizations and hospital days among the high risk population, OTA used NCHS data for the number of hospital discharges and lengths of hospital stay for persons with pneumonia as a first-listed diagnosis and a high risk condition as another diagnosis. OTA estimated the number of pneumonia ambulatory visits among the high risk population by arbitrarily assuming that the ratio of pneumonia ambulatory visits in the high risk population to visits in the general population would be the same as the rate of pneumonia hospital discharges in the general population.

of medical care for an average person. Similarly, it was assumed that a high risk individual would have twice as many days of pneumonia illness and twice as many days of non-pneumonia illness as a member of the general population. Finally, it was assumed that a high risk individual had two times the exponential probability of dying from all causes and almost two times the exponential probability of dying from pneumonia as did an "average" person. [9] The values for individuals not at high risk were adjusted accordingly.

The results of the high risk model obviously depend on the arbitrary selection of the multipliers that were used to adjust the base case data. The model, however, does illustrate the effect that differentiating by risk status can have on the results. Results from OTA's hypothetical model are shown in table 15. In each age group, the model shows that it is more cost-effective to vaccinate a person at high risk than a person not at high risk, and in some cases, vaccinating a person at high risk may even be cost-saving.

Table 15.—Hypothetical Per Vaccinee Cost-Effectiveness Ratios[a] for High Risk Vaccineesb Compared to Ratios for Non-High Risk Vaccinees

	Per vaccinee cost per QALY by age group				
	2-4 years	5-24 years	25-44 years	45-64 years	65 + years
High risk individuals	$21,300	$17,300	$7,300	$500	—[c]
Non-high risk individuals	$92,700	$82,300	$33,300	$10,600	$1,700

[a]The age-specific cost. effectiveness ratios that are shown, expressing the net per vaccinee societal cost per QALY gamed by a vaccinated individual, were calculated on the basis of more exact numbers for net costs and effects than those that appear in this table
[b]High risk individuals are defined here as individuals with medical conditions that place them at especially high risk of contracting o dying 'rem pneumococcal pneumonia In this analysis, it was assumed that for these Individuals, medical costs, days of illness, and an exponential probability of dying were twice those for non-high risk individuals (See footnote 9 below)
[c]For this age group, vaccination would be cost-saving

MODIFICATION OF THE SOCIETAL MODEL FOR MEDICARE

The discussion in the preceding sections has shown that, from a societal perspective and with the stated assumptions, a program of pneumococcal vaccination for the elderly is fairly cost-effective relative to vaccination for other age groups. From this discussion, one might be led to ask: How much would a pneumococcal vaccination program for the elderly cost Medicare? What changes in Medicare expenditures, if any, might result from pneumococcal vaccination among the elderly?

To answer these questions, OTA modified the model used to develop societal costs to calculate Medicare costs and savings that would be associated with a pneumococcal vaccination program. Medicare data provided the basis for projecting that, allowing for copayments and deductibles, vaccination would save Medicare about 75 percent of the hospital costs and about 55 percent of the physician costs it incurs for the treatment of pneumococcal pneumonia (Gibson, 1978). In addition, it was projected that Medicare would pay about 45 percent of the cost of medical care in extended years of life, plus 100 percent of the vaccination cost.

Results based on these percentages and the variable values used in the base case analysis suggest that if Medicare paid $11.37 for a pneumococcal vaccination of an elderly person, the program would incur a net expenditure per vaccinee of approximately $5.13 and add .004 QALY to the person's life.

'Actually, it was assumed that a high risk individual had 1.8 times the exponential probability of dying from pneumonia as a member of the general population. If a factor of "2" had been used in the model, a non-high risk person would need to have had a negative probability y of death in order to derive the "average" probabilities used in the base case model.

On the assumption that **21.5** percent of the population age 65 and older would be vaccinated (the 1975 rate for influenza vaccination), Medicare would spend approximately $26 million over the lifetimes of those vaccinated; this expenditure would yield about 22,000 QALYs. Medicare would spend approximately $58 million to vaccinate the elderly and would incur costs of approximately $10 million for the treatment of illnesses not prevented by vaccination in extended years of life. Because Medicare would save approximately $42 million in pneumococcal pneumonia treatment costs, however, it would incur an overall net expenditure of **$26** million.

In the sensitivity analysis, the results for the Medicare program change substantially. Substituting the sensitivity analysis values one at a time for the base case values yields a range of costs per vaccinee to the Medicare program varying from a net savings of $5 to a net cost of $17.

In terms of population costs, these figures translate into a range in Medicare costs varying from $14 million in savings to a high of **$56** million in expenditures. The savings figure is based on the assumption that the vaccine is administered through a public program at a cost per vaccination of $3.45. The high figure in positive net costs is based on the assumption that the number of pneumonia deaths in 1978 was equivalent to the number of deaths in which pneumonia was mentioned anywhere on the death certificate. When this assumption is made, a vaccination program becomes more costly, apparently because, as more deaths are averted, the cost of medical care in extended years of life increases. Regardless of whether pneumococcal vaccination of the elderly would save money for Medicare, however, such vaccinations would be likely to improve the health status of Medicare vaccinees.

The more completely a financing program such as Medicare covers the medical costs affected by vaccination, the more closely the program and the societal perspectives coincide. If Medicare were to pay a higher percentage of attendant medical costs for beneficiaries 65 years and older, then according to this CEA, expenditures to the program would more closely approximate societal expenditures. In OTA's model, Medicare's net costs would exceed net societal costs. Since Medicare pays only part of treatment costs, it would realize only part of the savings in treating pneumococcal pneumonia.

DISCUSSION OF RESULTS

The differences in pneumococcal vaccination cost-effectiveness ratios for different age groups generated in OTA's analysis and the sensitivity of the results to certain variables illustrate the benefits to be gained from targeting vaccination efforts. The cost-effectiveness ratio per vaccinee for all ages combined, with base case assumptions, would be $4,800 per QALY gained. Vaccinating an additional child aged 2 to 4 would buy a QALY for $77,200, while vaccinating an additional adult 65 years or older would gain a QALY for only $1,000. Thus, to increase the cost-effectiveness of vaccination, efforts could be made to provide the vaccine to the elderly and to discourage its use by healthy children.

This analysis also shows the sensitivity of the results to key variables such as the duration of immunity. According to current information, vaccination would be more cost-effective for the elderly than for others. If immunity proves to last longer than the 8 years assumed in the base case, however, it might be efficient to expand vaccination to other age groups. Otherwise, vaccination could be targeted only to older age groups.

The variation in cost-effectiveness by age suggests the importance of considering cost-effectiveness ratios for groups at high risk of contracting pneumococcal pneumonia or suffering complications from it. Besides age, the presence of certain chronic conditions may also characterize high risk groups. Sickle-cell patients, like others with malfunctioning spleens, seem especially susceptible to pneumococcal disease (Eeckels, 1976). One clinical trial has indicated that pneumococcal vaccine is efficacious for sickle-cell patients (Ammann, 1977). Pneumococcal vaccination may or may not be cost-effective for those in high risk groups other than the elderly. Although these groups would experience benefits from vaccination in reduced treatment costs for pneumococcal pneumonia and gains in life expectancy, these benefits might be offset by high costs for treatment of other illnesses and poor general health in extended years of life. OTA's hypothetical high risk model, however, did suggest that cost-effectiveness could be improved by targeting vaccination to high risk people.

The cost-effectiveness ratios generated in OTA's analysis apply only to vaccination against pneumococcal pneumonia. If the current pneumococcal vaccine is also effective in preventing other pneumococcal diseases, then benefits of vaccination are undervalued. A pneumococcal vaccine able to prevent other pneumococcal diseases, such as meningitis and otitis media, would raise additional possibilities. Not only improved health, but also any increases in the cost of such a vaccine would have to be considered.

The importance of a number of factors whose precise value is unknown was demonstrated in the sensitivity analysis. It is striking that for only two of these uncertain variables, i.e., the discount rate and the weighings for different health states used to derive QALYs, is choosing among alternatives a matter of value judgment or subjectivity. The selection of a discount rate reflects preference for the present compared to the future and return on other uses of funds. Similarly, weighting bed- and nonbed-disability is a matter of personal preference.

Ascertaining the actual value of most of the other variables in the model is an empirical problem. Better data on pneumonia mortality and morbidity, as well as data on the percent of pneumonia that is pneumococcal, are needed to establish the magnitude of pneumococcal pneumonia as a health problem. Pneumococcal vaccine's efficacy, duration of immunity, and adverse effects are matters of probability, but subject to fact-finding research. Projecting pneumonia deaths is an estimation problem dependent on data about historical mortality trends.

Results from this analysis could substantially change if two key assumptions proved to be wrong. In the base case analysis, it was assumed that the rate of efficacy for the vaccine remained constant for all age groups. It was also assumed that the percent of pneumonia caused by the types of pneumococci represented in the vaccine did not change among different age-specific and high risk populations. Neither of these assumptions can be supported empirically. Acceptable data that would either refute or validate either of these assumptions do not exist. Data generated from current NIAID-assisted clinical studies will help to answer questions about the vaccine's efficacy and usefulness in high risk populations.

---

[10]It is estimated that the incidence of sickle-cell disease among black births in the United States is 2.5 per 1,000 and that 98 percent of those with the disease in the United States are black. The age distribution of these people, however, is unclear (Gaston, 1978). Research by Powars indicates that sickle-cell patients are most at risk of pneumococcal disease during the first 5 years of life (Powars, 1975; Amman, 1977), One theory is that sickle-cell children, like other children, lack circulating anti bodies during their first 5 years and develop them gradually to the adult antibod, level by about age 10. Unlike other children however, sickle-cell pat i en ts and others with impaired spleens do not have splenic function as a second 1 ine of defense against infection. Sickle-cell children are thus more susceptible to pneumococcal disease and its complications u n t i I about age 10, by which t ı me their level of circulating antibodies has risen (Pearson, 1978). Clinical observations support this theory, because pneumococcal infection in sickle-cell patients declines markedly by age 9 (Powars, 1975).

The results of the sensitivity analysis could be used to help set priorities for research. One finding, for example, was that changes in the duration of immunity provided by vaccination produce substantial variations in the cost-effectiveness of pneumococcal vaccine. Unfortunately, no clinical data are available to permit accurate estimates of duration of immunity to be made. Furthermore, there is little, if any, research being conducted to assess this aspect of the vaccine. Because duration of immunity substantially affects the cost-effectiveness of the vaccine, persons deciding whether or not to fund pneumococcal vaccination programs could insist that clinical researchers place a high priority on answering this question. Another important challenge for future research is the assessment of the vaccine's efficacy among age-specific and high risk populations.

The per dose cost of pneumococcal vaccination had a substantial influence on the cost-effectiveness ratios. Although estimates for a public program formed the basis of the lower boundary on vaccination costs, the lower cost per dose, rather than the public program per se, affected the cost-effectiveness ratios, With a lower injection fee or vaccine price, privately provided vaccination could result in lower costs and more favorable cost-effectiveness ratios.

The general finding that cost-effectiveness ratios for pneumococcal vaccination improve with the age of the vaccinees results from a combination of factors: the incidence of pneumonia by age, the assumed duration of immunity, and the discounting procedure. From early middle age, pneumonia (and pneumococcal pneumonia) mortality and morbidity rates begin to climb. If immunity lasts 8 years, a vaccinee 65 years or older immediately benefits from reduced probability of contracting pneumococcal pneumonia. Vaccination also would render those 45 to 64 years less likely to contract pneumococcal pneumonia, but the limited immunity and discounting of future events reduce the benefits relative to costs for people 45 to 64 years. Younger vaccinees would have little immunity remaining when they reached the ages of greater pneumonia incidence and severity. Discounting has no effect on vaccination costs, which would occur in 1978, but reduces, from an economic perspective, the relative importance of improved health decades later.