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COST-EFFECTIVENESS OF THE EXPANDED PROGRAMME ON IMMUNIZATION IN THE IVORY COAST: A PRELIMINARY ASSESSMENT*

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Abstract—A preliminary calculation was made of the cost-effectiveness of the measles component of the Expanded Programme on Immunization (EPI) in the Ivory Coast. The calculation is based on existing data (program budgets, coverage surveys, counts of vaccinations provided and subjective estimates) and applies to the first three demonstration and training zones (Abidjan, Abengourou and Korhogo) with a combined population of 1.75 million people. The average annual cost of the measles program (assumed to be 75% of all EPI costs, including supplies, personnel and equipment) in these three zones was $527,000 at 1980 prices. Having achieved an average coverage rate of 61%, the cost per vaccinee was moderately high, $12. Yet, vaccinees are a sufficiently small part of the population that the cost per capita is only $0.30. The program is estimated to prevent 38,000 cases of measles and 1100 deaths per year in these three zones. Thus, the cost per measles case averted is $14, and the cost per death averted is $479. This means that the measles component of the EPI Program is highly effective in preventing deaths for the sums expended compared to many alternative health programs in developing countries.

Key words—child survival, cost analysis, cost–benefit analysis, cost–effectiveness analysis, developing countries, Expanded Programme on Immunization, immunizations, Ivory Coast, measles, primary health care, recurrent costs, vaccinations, West Africa

INTRODUCTION

The Expanded Programme on Immunization (EPI) is a world-wide effort to immunize children and pregnant women against several major vaccine-preventable diseases. In the Ivory Coast, where the EPI program began in 1978, children are vaccinated against tuberculosis, diptheria, pertussis, tetanus, polio and measles, and pregnant women are vaccinated against tetanus.

This preliminary assessment projects the cost-effectiveness through mid-1981 of the EPI implemented in three initial demonstration and training zones in the Ivory Coast—Abidjan (the capital), Abengourou and Korhogo—with a combined population of 1.75 million people. Abidjan is entirely urban; the other zones contain a main town and surrounding rural areas. This preliminary assessment has been constructed entirely from existing data (particularly budgets and program statistics) and expert opinion.

While the numerical results are necessarily tentative, this assessment does indicate how the kinds of preliminary estimates needed by officials of developing countries and donor agencies for many planning decisions can be generated in limited time (less than a week for data collection and analysis for the present study). Furthermore, it provides a framework for more systematic analysis. Indeed, Layes Sanoh in collaboration with the two other authors is conducting a more detailed study of the cost–effectiveness of the EPI with support from USAID through its Project for Strengthening Health Delivery Systems in Central and West Africa (Project SHDS).

The Ivory Coast is one of the more prosperous countries in black Africa. According to the Population Reference Bureau [1], it has a population of 8.0 million persons and a rate of natural increase in population of 2.9% annually. Although the Ivory Coast had a 1980 per capita GNP of $1150, its life expectancy at birth was only 47 years, and its infant mortality rate was relatively high at 154 per 1000 births [1–3].

In the Ivory Coast, the EPI is carried out using facilities and personnel of the Ministry of Public Health and Population, but it receives financial and technical support from several international sources in addition to the Government of the Ivory Coast.

For this preliminary assessment, attention was limited to only the measles component of the programme as measles was the leading cause of reported morbidity and overall disease burden among the diseases included in the EPI. Although reporting of disease is obviously incomplete, data are available from adjacent Ghana for 1975 which have been corrected for underreporting [4]. Ghana and the Ivory Coast are generally similar in climate, infant mortality rates (130 for Ghana and 154 per 1000 live births for Ivory Coast), birth rates (50 for Ghana and 48 for Ivory Coast per 1000 population per year), and life expectancy at birth (47 years for both countries). Thus, it does not seem unreasonable to extrapolate patterns of individual diseases from Ghana. There, overall disease burden has been measured in terms of days of life lost, a measure that combines temporary and permanent disability and premature death.

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Table 1. Burden of EPI diseases, 1975

Disease	Reported incidence in Ivory Coast*+	Estimates for Ghana‡ Incidence	Case fatality rate (%)	Days of life lost§	% Days lost
Measles	11.5	39.0	3.0	23.4	50
Tuberculosis	0.4	2.0	35.0	11.0	23
Tetanus (neonatal)	0.3	0.5	80.0	6.9	15
Pertussis	3.3	21.0	1.0	4.6	10
Polio	0.0005	0.2	5.0	1.2	2
Diptheria	0.07	0.01	7.0	0.01	0
Total	15.6	62.7	4.0•	47.1	100

*Reported cases for 1975 divided by estimated population of 6.4 million. Numbers of cases from Ministry of Public Health [5].
+Rate per 1000 population of all ages per year.
‡From Ghana Health Assessment Project Team [4].
§Thousands of days per 1000 population per year.
•Average rate weighted by incidence.

Because of its substantial disease burden, measles vaccination was assumed to form the main impetus for the EPI program. Thus, all joint costs required for the program operation for any disease were initially allocated to measles immunization. Other diseases were allocated only their incremental cost, given that an immunization program was in operation. Based on the cost of components of the program, it was estimated that up to 75% of all EPI costs in the Ivory Coast were attributable to the basic costs of setting up a program and offering measles vaccine. The remaining 25% could be attributed to the cost of offering the other vaccines. As this procedure allocates a greater share of costs to measles than its share of projected disease burden, this preliminary analysis would likely be less favorable than one that considers all the EPI vaccines*.

Alternative methods would allocate a lower share of joint costs to measles. A study from the Gambia [6], which allocated EPI costs in proportion to actual vaccination contacts, attributed only 9% of the Gambia program costs to measles. If all children and women received every recommended vaccination, measles would be allocated one-seventh (14%) of the total program costs. If costs were allocated uniformly among the six antigens, then the share for measles would have been 17%.

*The most methodologically rigorous approach would have been to avoid the problem of joint costs by performing a cost–effectiveness analysis of the entire EPI program, rather than just its measles component. This approach would respond directly to the major policy decision of whether to mount an entire EPI program in a region or country. The comprehensive approach would, however, require estimating health benefits of all EPI antigens in a common numerical scale, such as death-equivalents averted. Since the epidemiology and the effectiveness of the vaccines are less well known for several of the other diseases, such an analysis would be complex and uncertain. In addition, it would require converting cases of paralytic polio into an equivalently valued number of infant deaths. These extensions are beyond the scope of the present analysis. This approach would give results identical to those obtained by allocating costs to measles in proportion to its disease burden. As this paper probably allocates a greater share of share of costs to measles, the overall cost–effectiveness of EPI would probably be more favorable than the results for measles alone.

Nevertheless, the higher allocation in this paper seems reasonable for several reasons. First, the cost per dose (10¢ if purchased from UNICEF) is higher than that for other vaccines. Second, it had been one of the most temperature sensitive vaccines (although more stable vaccines were started in 1980), so that much of the expense of maintaining the cold chain is due to measles. (Measles requires both freezers and refrigerators, whereas most other vaccines are not frozen.) Third, up through 1980 the costs of promoting vaccinations were due largely to measles. Recruitment is easier for the other vaccinations. BCG vaccination is given at birth, so coverage is virtually universal for children born in maternities. Similarly, mothers receiving prenatal care form an accessible population for tetanus vaccination. DPT and polio are begun at the third month, while a mother is still very concerned about the health of the infant and brings him regularly for visits. Measles vaccine, however, cannot be given until 9 months or later because the vaccine is not very effective at younger ages due to maternal antibodies transferred in breast milk [7]. But by the age of 9 months, a mother may already be pregnant with her next child and be less inclined to bring her infant for vaccination. Thus, the costs of posters, puppet shows and loudspeakers used to draw attention to vaccinations, and of staffing to assure that vaccinations are offered at convenient times and places, should be attributed disproportionately to measles. In 1981, the Ivory Coast EPI Program began (with considerable success) administering measles vaccinations to children at the time of treatment visits for other complaints, so the allocation of joint costs to measles would be lower now.

ASSESSMENT OF COSTS

Table 2 lists material budgets (equipment, fuel, supplies, travel and miscellaneous) for the entire Ivory Coast EPI Program by source and year established at the initiation of the program in 1978. This budget is assumed to apply only to the original three demonstration zones and to match actual outlays on average. Over time, the contribution of the Government of the Ivory Coast rises and that of donors declines.

While some of these expenditures are for equipment with a life of several years (such as vehicles and

Table 2. Material costs of EPI Program in original demonstration areas of Ivory Coast, by year and source of funds (in US$ at 1978 prices)

Source	1978	1979	1980	1981
Ivory Coast Government	78,200	89,000	104,000	142,000
USAID	126,000	70,000	92,000	60,000
UNICEF	68,000	40,000	35,000	14,000
Total	272,200	199,000	231,000	216,000

refrigerators), it assumed that expenses over these 4 years apply entirely to vaccinations effected over these years. For expendable supplies, such as vaccines and fuel, this procedure is completely appropriate. For equipment, the best procedure would be to annualize the costs of all equipment used (including existing equipment of the Ministry) over their expected useful lifetimes. Because of data limitations, equipment costs had to be treated on a cash basis in this preliminary assessment. While this simplification overstates the cost of equipment purchased, but not worn out during the demonstration project period, the error is somewhat offset by not including the value of pre-existing equipment (particularly vehicles and workshops existing prior to the EPI programs).

To combine the costs incurred over the 4 years, they are converted to present value by discounting future year costs. A study of the Ivorian economy by Linn [8] estimated that most likely value of the real discount rate (the accounting rate of interest) was 8.5% per year. Possible values could range from 5.9 to 10.2%. Discounting material costs at the rate of 8.5% per year, yields a present value program cost of $820,900 as shown below:

$$\frac{272,200}{1}+\frac{199,000}{(1.085)^1}+\frac{231,000}{(1.085)^2}+\frac{216,000}{(1.085)^3}=\$820,900.$$

To simplify the analysis below, these expenditures on material are annualized. The annualized expenditure is the constant amount, x, which, if spent each year would have the same present value as that calculated above. Replacing the actual expenditures above by x on the left hand side gives x (termed the annualized cost) equals $230,990. The annualized cost is relatively insensitive to the discount rate. That cost ranged from $230,552 at a discount rate of 5.9% to $231,274 at a discount rate of 10.2%. Since aggregate costs in this analysis are rounded to the nearest thousand dollars, the choice of discount rate makes no practical difference here.

The annual cost of expatriate personnel is $160,000 and that of local personnel $212,000, for a total of $372,000. It has also been assumed that the cost of amortizing buildings represents 17% of non-building costs (material and personnel costs), i.e. $100,000. This share is based on the corresponding ratio of 24% that Creese [9] derived for the EPI program in Thailand, adjusted for the high volume of immunizations and small share of space in busy health facilities in Ivory Coast devoted to EPI. Thus the total annual cost of the EPI in the original zones if $703,000 of which personnel constitute 53% (30% national and 23% expatriate), supplies, equipment and transportation constitute an additional 33%, and building upkeep constitutes the remaining 14%.

Using the 75% allocation, the cost attributable to measles is 75% of $703,000, or $527,000 per year. This estimate of resources used for the measles component of EPI includes both expenses incurred specifically for this program (such as vaccines and equipment) and the value of existing resources allocated to EPI (such as the time of local personnel). The net cost of measles vaccination would be less than this gross cost, because treatment costs related to measles cases averted would be avoided.

EFFECTIVENESS OF THE PROGRAM

The first measure of effectiveness is the number of children in the target age range vaccinated. Two methods are available for estimating this number.

The direct method is to employ counts aggregated from tally sheets of vaccination sites of number of vaccination given each day. In the three original zones the average number of measles vaccinations for 1979–1980 is about 91,000 [10].

A second estimate is obtained from assessing vaccination coverage based on cluster surveys of children in randomly chosen households. A standard procedure has been developed by WHO for this purpose, and such surveys have been conducted periodically by program managers in the three zones. The results, from Ivory Coast EPI [10] are shown in Table 3. The

Table 3. Vaccine coverage rates from household surveys, by year

Zone	1980 Population	1979	1980	1981
Abidjan	1,500,000	51%	61% June	53% June
Korhogo	100,000	NA	37% May	NA
Abengourou	150,000	71% May	73% and 79%* June	NA
Total	1,750,000	—	61% (weighted)	—

*Of the two 1980 rates reported for Abengourou, the lower one was used for subsequent analysis.

NA—not available (no survey).

average coverage in 1980 was 61% of children in the target age range.

Based on a crude birth rate of 48 per 1000 population [1], there were 84,000 births among the 1.75 million people in the original demonstration zones. The infant mortality rate is 154 per 1000 live births, and most of these deaths occur early in the first year. Thus, about 85% of live births (71,000 infants) survive to the recommended age of vaccination (9–12 months). The average coverage in these zones was 61%, so 43,000 children would have to receive measles vaccine each year (61% of 71,000) to give the coverage observed. As the direct count of 91,000 may include children outside the appropriate age range and repeat vaccinations, the more conservative estimate of vaccinations (43,000) is adopted for later analysis.

The effectiveness of measles immunizations in preventing morbidity can be inferred from an epidemiological model. Assuming that herd immunity is not important, then the effectiveness fraction (fraction of cases prevented) in vaccinated children is calculated [11]*:

$$\begin{array}{c}\text{Effectiveness}\\ \text{fraction}\end{array} = \begin{array}{c}\text{Diagnostic}\\ \text{accuracy}\end{array} \times \begin{array}{c}\text{Efficacy}\\ \text{rate}\end{array} \times \begin{array}{c}\text{Provider}\\ \text{compliance}\end{array} \times \begin{array}{c}\text{Patient}\\ \text{compliance}\end{array}.$$

In this conceptual model, diagnostic accuracy refers to whether the need for vaccination was appropriately 'diagnosed'. For practical reasons, vaccinations are offered to all previously unvaccinated children from the age of 9 months onward. The fraction of susceptible children 9–24 months of age was 91.7% in the study by Breman *et al.* [7]. While this study was done in rural villages, where measles is generally contracted later than in urban areas, the age range is much broader than that recommended for measles vaccination (9–12 months). Thus, these data should be representative for the current program. The diagnostic accuracy is then the percentage of children suceptible when offered vaccination, here estimated as 92%.

The efficacy rate is the percentage reduction in morbidity under ideal conditions in a susceptible vaccinated child, compared to an unvaccinated susceptible child. A study by Breman *et al.* [7] of antibody titres of Ivory Coast children before and after measles vaccination estimates the efficacy rate by the rate of sero-conversion as 0.95 in children 9–24 months of age. Sero-conversion is assumed to be tantamount to clinical protection. A randomized clinical trial in England found that clinical protection rates against measles were almost as high (93% with live vaccine, 89% with killed vaccine) [13]. Thus, the efficacy rate found by Breman *et al.* is possible under ideal conditions.

Provider compliance is the extent to which the practices of health providers in actual field conditions replicate ideal practices under which efficacy was established in a research trial. The main issues in provider compliance are adequate maintenance of the cold chain to assure that the vaccine is potent and the dose is correct. This assumption could be validated with field studies of sero-conversion rates or direct studies of vaccine effectiveness. The latter could be accomplished by investigating outbreaks of measles in villages in which some of the children had been vaccinated, or through appropriate case-control studies. At present, however, there are no such usable data from the Ivorian EPI program. In this preliminary study, provider compliance is assumed to be 100%, as the 1981 evaluation of EPI in the Ivory Coast found the cold chain to be generally well managed.

Patient compliance is the extent to which patients follow ideal practices, such as returning for subsequent doses of a vaccine. As only one dose is required for measles vaccination, patient compliance is automatically 100% within the covered population. Another factor of provider and patient behavior, obtaining the vaccination at the correct age, was incorporated earlier under diagnostic accuracy. Overall, the effectiveness fraction is $0.92 \times 0.95 \times 1.00 \times 1.00 = 0.87$ or 87%.

This effectiveness fraction can now be applied to estimate the impact fraction in childern surviving to 9 months, and number of cases prevented. The formula are:

$$\begin{array}{c}\text{Impact}\\ \text{fraction}\end{array} = \text{Coverage} \times \begin{array}{c}\text{Effectiveness}\\ \text{fraction}\end{array}$$

and

$$\begin{array}{c}\text{Cases}\\ \text{prevented}\end{array} = \begin{array}{c}\text{Baseline}\\ \text{population}\\ \text{size}\end{array} \times \begin{array}{c}\text{Baseline}\\ \text{incidence}\\ \text{rate}\end{array} \times \begin{array}{c}\text{Impact}\\ \text{fraction.}\end{array}$$

Defining the target population to be a cohort of newborns who survive to 9 months, the incidence in that cohort is virtually 100%. That is, measles is so endemic and contagious that every child is virtually certain to contract measles in the absence of protection. Applying these formula gives

$$\begin{array}{c}\text{Impact}\\ \text{fraction}\end{array} = 0.61 \times 0.87 = 0.53 \text{ or } 53\%,$$

and, assuming negligible levels of immunization before the EPI program,

$$\begin{array}{c}\text{Number of cases}\\ \text{prevented}\end{array} = 71{,}000 \times 1.00 \times 0.53$$

$$= 38{,}000 \text{ per year.}$$

Then the number of deaths averted is estimated as:

$$\begin{array}{c}\text{Number of deaths}\\ \text{averted}\end{array} = \begin{array}{c}\text{Number of cases}\\ \text{averted}\end{array} \times \text{Case fatality rate.}$$

*Herd immunity means that so few persons in the cohort are susceptible that the spread of disease will eventually fall to almost zero. Makinen's [12] epidemiologic model for Cameroon found that the level of vaccination coverage needed to eventually stop the spread of measles would have to be at least 59%. With high rates of population mobility, even this moderate level of coverage (which is already beyond that found in most of the demonstration zones in the Ivory Coast) would be insufficient. Thus, unvaccinated children in the Ivory Coast are likely to contract measles.

Among 1396 hospitalized measles cases in Abidjan in 1980, there were 117 deaths, a case fatality rate of 8.4% [10]. Because cases attended in medical facilities should be above average in severity, the case fatality rates that apply to the population as a whole should be lower. Morley [14] has estimated the case fatality rate in West Africa based on available literature as 3–5%. The Ghana Health Assessment Project Team [4] used 3% for Ghana, the value chosen here for subsequent calculations. Thus the estimated number of deaths averted in the demonstration zones is 38,000 cases × 0.03 case fatality rate, or about 1100 deaths per year. It is interesting that the weighted reduction in the number of in-hospital measles deaths (weighting the three zone by their populations) was 50% between 1978 and 1980, a change extraordinarily close to the 53% reduction predicted by the epidemiological model.

In a controlled trial of measles vaccinations in Zaire, the total mortality rate (from all causes) in children aged 7–35 months was 30% percent lower in a community offered measles vaccinations (Group 1) compared to a comparable community not offered vaccinations (Group 2) [15]. Measles probably accounts for half of all deaths of children under 3 in the Ivory Coast. If no other causes of death were affected, the epidemiologic model predicts a 27% reduction (half of 53%) in total deaths. Since measles vaccination also appears to protect against diarrhea [16], this reduction in mortality may be a conservative estimate. This predicted percentage seems to agree remarkedly well with results of the Kasongo project.

While the agreement between the model and actual reductions adds reductions adds some validity to the epidemiological model, it is partly coincidental. Because of epidemics, yearly in-hospital measles deaths have varied by a factor of two in Abidjan over 1976–1981. The observed reduction would need to be sustained over several years before it could be confidently attributed to the vaccination program.

YEARS OF LIFE ADDED

Since deaths from measles occur at the age of 1 year on average [4], each death averted represents a substantial number of life years added. To quantify this addition, one needs to know the life expectancy of a child saved from measles death. If the child who would have died from measles at 1 year were an 'average' child, he should gain the average life expectancy of a 1-year-old child. Life expectancy at age 1 is greater than life expectancy at birth, because the 1-year-old has survived the high rate of infant mortality. In Ghana the life expectancies were 52.4 years at age 1 vs 46.9 years at birth [4]. On the other hand, the child who would have died of measles is not necessarily an average child. Because malnutrition is a strong risk factor in death from measles [14], children who would have died from measles but are saved by vaccination likely face higher mortality than other children of the same age. In the extreme, if measles killed only those children who were doomed to die soon of other causes, the gain in life expectancy from measles vaccination would be trivial.

Findings of the Kasongo Project Team [15] indicated that measles vaccination was indeed associated with a 43% excess in death rates at later ages (Group 2 compared to Group 1 for children aged 22–35 months), but the number of lives saved earlier far outweighed the additional deaths later; overall, the death rate from 7 to 35 months was 30% lower in the community offered vaccination. For further discussion of interactions between risk factors and competing causes of death, see Shepard and Zeckhauser [17].

For this analysis, we assume that the excess risk experienced by children 'saved' from measles death are comparable to the risks during the first year of life. Therefore, we assume that children whose death is averted by measles vaccination gain the average life expectancy at birth (rather than at age 1) in the Ivory Coast, i.e. 47 years.

The gain in life expectancy at birth for all children born in the demonstration zones is:

$$\frac{\begin{pmatrix}\text{Number of}\\ \text{deaths averted}\end{pmatrix} \times \begin{pmatrix}\text{Years added per}\\ \text{death averted}\end{pmatrix}}{\text{Number of newborns in annual cohort}}$$

or

$$\frac{1100 \times 47 \text{ years}}{84{,}000 \text{ newborns}} = 0.62 \text{ years per child born.}$$

This is equivalent to 225 days (365 days × 0.62) of normal life, most of which are healthy. Such a large gain from a single health intervention is impressive.

DISCOUNTED YEARS OF LIFE

For many cost–effectiveness and cost–utility comparisons, a useful measure of health gains is discounted years of life. The rationale for discounting of life years is that an individual, and a society, generally prefer saving life years sooner rather than later, in the same way that societies prefer other desirable goods sooner. The rate of time preference for years is often chosen to be equal to the rate of time preference for money (the accounting rate of interest in developing countries), although the two rates need not be equal [18]. To estimate the number of discounted years of life gained, we used the same rate of time preference as used for money, 8.5% per year*, and used model

*If an individual has the same rate of time preference for years as for money, he will always be willing to exchange the same amount of money for a year of life. If an individual's real income rises, however, he might be expected to exchange more money for a year of life. Thus, his discount rate for years could be less than that for money. Suppose, for example, that the rate of time preference for years were 3% lower than that for money (i.e. 5.5% per year for years, 8.5% for money). This could arise if the income elasticity of demand for years were 1.0 and real income was rising at 3% per year. Then discounted life expectancy would be some 40% higher than the base case value. Thus, the choice of discount rate for years used here appears to be conservative; alternative values lead to even more favorable cost–effectiveness ratios. A still more thorough analysis would incorporate changing time preference rates with time and age.

life-tables for West Africa for males and females calibrated to 45 years [19] as the closest available approximation to a life table for the Ivory Coast. (The country's life expectancy at birth was actually estimated as 47 years in 1980 [3]. For the discounted calculation, we ignored any excess risks faced by children 'saved'. Then the gain in life expectancy for a death averted at age 1 translates to 9.7 discounted years. (Without discounting, life expectancy at age 1 would have been 51.4 years.) The increase in discounted life expectancy for the entire cohort of newborns is:

$$\frac{1100 \text{ deaths averted} \times 9.7 \text{ discounted years}}{84{,}000 \text{ newborns}} = 0.13 \text{ discounted years.}$$

UNIT COSTS

Two measures of unit cost are of interest for assessing the affordability of this program, and for comparing the efficiency of alternative methods for delivering vaccinations. First, the cost per infant vaccinated against measles is:

$$\text{Cost per vaccinee} = \frac{\$526{,}000}{43{,}000 \text{ vaccinees}} = \$12.30.$$

This is similar to the cost per infant vaccinated against measles in Zambia in 1977 found by Ponnighaus of $4.55–$8.51 [20].

Second, the cost of measles vaccination per capita in the population is:

$$\text{Cost per capita} = \frac{\$527{,}000}{1.75 \text{ million persons}} = \$0.30.$$

By contrast, the overall per capita health expenditure of the central government is $14 [3]. Thus, the cost per person who actually receives a vaccination is relatively high, whereas the cost per person in the population is modest. The reason is that costly vaccinations need be given only once (or for only one sequence) in a lifetime, and are thus directed to a small segment of the population.

If all children vaccinated against measles also received the other EPI vaccinations (the most favorable assumption), the cost per fully immunized child in the Ivory Coast would be about $16. This is considerably higher than the WHO global planning estimate of $3 per fully immunized child. Studies of the EPI program in other countries using costing guidelines developed by Creese [9] have found the cost per fully vaccinated child to be somewhat lower—$2.80 in the Phillippines in 1978, $2.30 in Indonesia in 1980 and $6.20 in Thailand in 1980 [21]. These lower costs compared to the Ivory Coast are explained in part by the fact that at the time of the costing studies, these programs included only two doses of DPT vaccine and omitted the use of polio vaccine and, in the Philippines and Thailand, omitted measles vaccine as well. The more detailed study underway in the Ivory Coast, as well as studies elsewhere, will help to refine the Ivory Coast figures and the global planning estimates.

COST-EFFECTIVENESS RATIOS

Cost–effectiveness analysis relates the health benefits of a program to its costs to facilitate comparison with alternative uses of the same funds within the health sector [18]. The cost per case averted in the cohort is calculated by dividing the total program cost by the number of cases averted, i.e.

$$\text{Cost per case averted} = \frac{\$527{,}000}{38{,}000 \text{ cases averted}} = \$13.90$$

The cost per death averted is calculated by dividing the total cost by the number of deaths averted, i.e.

$$\text{Cost per death averted} = \frac{\$527{,}000}{1100 \text{ deaths averted}} = \$479.$$

The cost per year of life added is calculated by dividing the cost per death averted by the number of years of life added per death averted. Either undiscounted or discounted years of life can be used. Thus,

$$\text{Cost per undiscounted year added} = \frac{\$479/\text{death}}{47 \text{ years/death}} = \$10.20,$$

and

$$\text{Cost per discounted year added} = \frac{\$479/\text{death}}{9.7 \text{ discounted years/death}} = \$49.40$$

These cost–effectiveness ratios can be used as a basis for comparison of a measles vaccine program with other programs that the Ivory Coast Government or foreign donors could support. As the authors are not aware of studies of any such programs for the Ivory Coast, the closest substitute available was illustrative programs from other developing countries, as shown in Table 4. Where an author gave a range of costs and health effects, the midpoint has been chosen. For greater comparability, costs have been adjusted for obvious reported exclusions (such as the salary cost of government health workers). Where necessary, results were converted from national currencies to U.S. dollars at the market exchange rate at the time of the study. The dollar cost at the time of the study was inflated to 1985 U.S. dollars by increasing by 10% per year, compounded, to approximate U.S. inflation over the past decade. Differences in general price levels among developing countries probably do not markedly affect costs of programs like EPI, since over half of the costs were for imported goods and services (supplies, equipment, and expatriate technical assistance). Differences in program organization may be important to cost, but further adjustments are not possible from the available data.

For example, a cost analysis of other immunization programs by Creese *et al.* [22] found that the cost per immunized child varied seven-fold among health centers within the same country, due primarily to the size of the catchment populations and the productivity of the immunization teams.

Table 4. Cost–effectiveness (CE) of selected health interventions in developing countries (1985 US$)*

Rank by CE	Intervention, country and source of data	Annual cost per capita	Annual deaths averted per 100,000 pop	CE (cost per death averted)
1	EPI (Indonesia)†‡	$0.07	35	$210
2	Oral rehydration therapy (Indonesia)§	$0.19	81	$230
3	Oral rehydration (Zaire)†¶	$0.24	75	$320
4	DDT spraying against malaria‖	$3.54	800	$440
5	Home-distributed oral rehydration solution packets (Egypt)**	$0.63	120	$540
6	Measles vaccination (Ivory Coast)††	$0.53	63	$850
7	Pilot projects in primary health care‡‡	$5.85	406	$1400
8	Non-DDT spraying against malaria‖	$26.58	800	$3300
9	Community water and sanitation (subsaharan Africa)‖	$4.03	104	$3900
10	Nutrition supplementation for children (Narangwal, India)‖	$3.10	58	$5300

*All costs were inflated to 1985 US$ assuming 10% annual inflation since year of study. The denominator population used for costs and deaths averted is the number of persons of all ages in an area with access to the intervention. For ORT interventions, costs and deaths averted were initially reported per child under age 5 in the population. These results were converted to per capita values by multiplying by 15%, the approximate share of the population under age 5.
†Indicates projection for a proposed program. Other entries are data from actual programs.
‡Barnum *et al.* [23].
§Shepard *et al.* [24].
¶Hogan [25].
‖Walsh *et al.* [26] for sub Saharan Africa.
**Derived from Mobarak *et al.* [27], adjusted for imputed salary to government health workers.
††Shepard *et al.* (present paper).
‡‡Evans *et al.* [28].

Under the assumptions made in this paper, the cost per death averted places EPI among the more cost–effective interventions. Given the preliminary nature of both the present assessment and many of the other examples in Table 4, the results should be taken only as general indications. The other EPI program analyzed [23] suggests a lower cost per death averted than our results from measles vaccination in the Ivory Coast. His projection of the cost per fully vaccinated infant (BCG, diptheria, pertussis, tetanus for infant and mother) was $3.69. In his analyses, both costs and effectiveness are projections developed prior to the start of the program and may underestimate the costs of actual program implementation.

Since vaccination programs are paid largely through public funds, distributional considerations are important. A measles vaccination program takes money from adult taxpayers in the Ivory Coast and donor countries and benefits children in the Ivory Coast, particularly those resident in the three demonstration zones who are at greatest risk of death from measles. Squire and van der Tak [29] have developed a method to include distributional consequences in a project appraisal in which benefits are weighted inversely to the income of the household receiving them. It is not possible to quantify the effect of measles vaccination on income distribution.

It is striking how cost–effective all of the programs on this list are compared to routine health and safety measures in developed countries. For example, the installation of seat and shoulder belts has been mandatory in automobiles sold in the United States for almost two decades. Yet this requirement costs an estimated $500,000 per life saved, a value close to that for many other health and safety efforts in developed countries [30].

COST–BENEFIT ANALYSIS

We have constructed an elementary cost–benefit analysis from these findings. A cost–benefit analysis values all program benefits in monetary terms. The direct benefits are savings in future treatment costs. An earlier West African study estimated that virtually all children with measles would receive at least outpatient treatment [31]. Vaccination coverage surveys in the areas of Korhogo and Ferkessedougou in 1982 confirmed this pattern. Rey *et al.* [31] also estimated that 5% of children with measles would be hospitalized. Adjusting Rey *et al.*'s West African prices [31] for inflation by the Ivory Coast's trend in the Consumer Price Index [2] and converting to dollars gives a 1980 cost per episode of $6.27 for outpatient treatment and $188 for inpatient care. The overall average is $15.67 per episode. For the three demonstration areas, the direct benefits are $595,000 per year ($15.67 per case × 38,000 cases averted).

The direct benefits alone exceed the costs of the measles vaccination program by 13%. This calculation may, however, overstate the true benefits both because costs in government health facilities probably did not rise as quickly as the Consumer Price Index, and because health resources not used for treatment of measles episodes are not necessarily saved nor made available for other uses.

The indirect benefits of preventing cases of measles are avoidance of short term morbidity and premature death. As the analysis by the Ghana Health Project Assessment Team [4] found that 96.6% of the potential days of life lost due to measles was from premature death, this cost–benefit analysis has focused exclusively on this component. Of the several possible methods for establishing the economic value of averting a death, we have chosen the 'human capital' or 'livelihood' approach, since it is the most widely used. Under this method a life is valued as the present value of the person's marginal lifetime contribution to the country's economic output. The conventional approach of using discounted earnings is not appropriate for developing countries in which certain wage rates may be considerably above the value of the marginal product.

To estimate an individual's marginal product, we began with the facts that the Ivory Coast's 1980 GNP is $1150 per capita [3] and that factor payments to labor represent 94.2% of the country's GDP [8]. We made the simplifying assumption that only half the residents of the Ivory Coast were age 15 or older and were economically active. Thus the average earnings per economically active person is $2167 ($1150 × 94.2% × 2).

Next, we obtained the ratios of the shadow wage rate to the actual wage rate for various sectors of the labor force. (The shadow wage rate is an estimate of the marginal product of labor.) These ratios ranged from 0.31 for urban unskilled workers in the informal sector to 0.83 for workers in the formal sector. We averaged the ratios for each sector, weighted according to the total earnings of that sector. The weighted average is 0.77. The marginal product per economically active person is $1670 ($2167 × 0.77).

Assuming that the variation in earnings with age can be ignored, the present value at age 1 of future lifetime earnings for a child alive at age 1 year is $4710, based on the previously used life table [19]. This is the economic benefit per death averted. This benefit is reduced to only 2.82 times the annual marginal product of an economically active individual because of discounting and the risk that an individual will not survive through adulthood. The indirect benefits of the measles component of the EPI program in the three demonstration and training zones total $5.18 million (1100 deaths averted × $4710 per death averted).

Together the direct and indirect benefits add to $5.78 million; they give a very impressive benefit–cost ratio of

$$\$5.78 \text{ million}/\$527{,}000 = 11.$$

Even if the direct benefits were considered severe overestimates and were excluded, the benefit–cost ratio would still be

$$\$5.18 \text{ million}/\$527{,}000 = 9.8.$$

This cost–benefit analysis suggests that in a country where measles is often fatal, measles vaccination is highly advantageous.

In other African countries a benefit–cost analysis would probably be less favorable, since the average earnings would probably be less and the ratio of the shadow wage to the actual wage would probably be lower. Despite the high rate of natural increase, the Ivorian economy has been able to employ its own workforce as well as migrants from neighboring countries.

It is interesting that a cost–benefit study of measles vaccination in the United States also found a benefit–cost ratio of 10 to 1 [30]. The higher economic value per death or complication in this country were offset by lower incidence rates.

PROJECTIONS OF RECURRENT COSTS OF A NATIONAL PROGRAM

The Ivory Coast envisages gradually enlarging the number of zones covered by EPI to reach the whole country by 1985. As of 1981, the program was already operating in zones containing 40% of the country's population.

A simple projection of costs of a national program is easy to make. The three demonstration zones contain 1.75 million out of the country's 8.0 million persons (1980 population), 21.9%. If the costs per infant of a national program were the same as those in the initial demonstration zones, the cost of a national measles program in 1980 prices would be $527,000/0.219 = $2.4 million per year. Similarly, the cost of a national complete EPI program would be $703,000/0.219 = $3.2 million per year. Probably these estimates are conservative, as two of the zones, Abidjan and Abengourou, are particularly easy to reach and have especially dedicated and competent management. These qualities might be difficult to replicate at the same level in a national programme, so costs might be higher and effectiveness lower than projected.

Assuming a national EPI program would cost $6 million annually at 1980 prices (a doubling of the naively extrapolated cost), it would represent only a tiny share (0.2%) of the total government budget, and a modest (5%) share of the central government's health budget [3]. Within the budget for preventive and rural health services, however, it would represent a much larger share. Thus, it would appear that Ivory Coast probably can afford a national EPI program, but a major reallocation of funds within the Ministry of Public Health will be required if other programs in preventive and rural health care are not to be drained.

Studies comparing differing ways of delivering EPI (e.g. the choice of fixed centers vs mobile teams) may identify ways of making the EPI still more cost–effective. Nevertheless, extrapolating from the experiences in other developing countries suggests that the measles component of the EPI programme in the Ivory Coast is already a cost–effective use of health resources.

Cost–effectiveness should not be viewed as the sole criterion comparing measles vaccination against other health interventions or choosing the best strategy for implementing vaccinations. Other factors may include consistency with national policies, equity, private costs and unquantified costs and benefits. Suppose, for example, that in some area a mobile team approach to vaccinations could avert deaths for $300 each while a fixed center approach costs $600. Suppose, however, that other factors (such as development of medical care infrastructure) favored the fixed center approach. Then the decision maker should determine whether the unquantified benefits of fixed centers are sufficient to justify twice the expenditure or half the number of deaths averted. If not, the mobile center approach remains best. Cost–effectiveness analysis thus serves both as an important yardstick in deciding how to allocate resources, and as a useful framework for incorporating non-quantified factors.

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