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ABSTRACT

Within the parameter of a given level of expenditure on the educational system as a function of time, this cost-effectiveness analysis examines all feasible ways of providing schooling in developing nations to see what levels of output each alternative method entails. Both technological and conventional alternatives are considered: degree of physical decentralization of the system; mix of instructional methods, including conventional instruction and the use of technology; time spent by the student in school in hours per day and days per year; the curriculum mix; and promotion, retention, and certification procedures. The costs of the alternatives are discussed, followed by a brief review of what is known about the alternatives in terms of their effects on student learning. Performance and cost information are then drawn together into a mechanism for evaluating alternatives in terms of a simple model of student progress through a school system. The paper concludes with two appendixes: the first surveys the literature concerning the benefits of education, and the second uses the developed model for an example cost-effectiveness analysis of elementary education in Indonesia. (Author/SL)

NOTES ON COST-EFFECTIVENESS EVALUATION OF SCHOOLING IN DEVELOPING COUNTRIES*

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I. INTRODUCTION

Educational planners have had a tendency to spend most of their time investigating questions of the following sort: How many secondary school graduates should be produced in year t ? How many primary? How many engineering? What is the appropriate level of expenditure on the educational system as a whole? To answer these questions properly it is necessary to gather evidence concerning the costs and benefits to society of different educational activities; this is cost-benefit analysis. Cost-benefit analysis seeks to answer questions like "Is item X an educational product worth producing and, if so, what quantity should be produced?" Most of the research in this area concerns attempts to categorize and measure the economic (and other) benefits improved education entails. On the cost side of the analysis, cost-benefit studies have tended to take costs as given, implicitly assuming that present (or past) costs reflect efficient methods of production. The role of cost-effectiveness analysis is to examine just what the efficiencies of alternative methods of production might be. The output of a cost-effectiveness analysis is tentative recommendations concerning how to produce the desired outputs. Cost-effectiveness analysis is concerned with minimizing the cost of obtaining a given set of outputs -- efficient production -- rather than with deciding what set of outputs to produce.*

My purpose in this paper is to outline a framework for cost-effectiveness evaluation of schooling in developing countries. I will

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*Philip Coombs [1970, p. 55] makes much the same distinction as the one I have drawn between cost-benefit and cost-effectiveness analysis; in referring to the education sector, he names the former "macroplanning" and the latter "microplanning". Emphasizing that insufficient relative attention has been paid to microplanning, Coombs suggests on p. 46 that "...educational planning now needs to get down inside the system and change it to make it more relevant and efficient and productive. This is the main way to raise the future rate of return on educational investments."

thus leave aside any discussion of the benefits of education though in Appendix A I provide a brief review of the literature on assessment of benefits. The present paper is further restricted in that it deals with cost-effectiveness evaluation of alternative ways of providing schooling in developing countries; it does not attempt to deal with all the alternative activities possible for school-age children. Thus it does not consider such issues as: What fraction of school-age children should be allowed to attend school? Should the school entering age be increased so that the economic benefits of education occur more quickly after the investment is made? Should schools be dispensed with altogether and the children taught at home by media? A number of these are critically important issues, but they fall outside the scope of a cost-effectiveness evaluation of alternative techniques for providing schooling.

A cost-effectiveness evaluation can proceed in either of two ways. In the first way the numbers of graduates of different levels, curricula, and quality that are demanded of the educational system are taken as parameters, and the analysis seeks to identify how the minimum cost way(s) of satisfying the demand depends on the parameters. The alternative way of proceding is to let the exogenous parameter be the level of expenditure on the educational system as a function of time; the analysis then examines all alternatives feasible within that budget constraint to see what levels of output they entail. These two ways of approaching the problem are what economists call "dual" in the sense that the technique that maximizes output for a fixed cost will be the same as the technique that minimizes the cost of producing that level of output. Thus from a theoretical point of view it matters little which approach is chosen, and one is free to choose on the basis of practical simplicity or convenience. I find the second approach -- that of fixing expenditures and attempting to delineate the range of feasible outputs -- more appealing, and that will be the approach used in this paper.

Section II formulates the alternatives available in terms of the budget as the basic constraint; both technological and conventional alternatives are considered. The costs of the alternatives play an important role in formulating the budget constraint, and costs are further discussed in Section III. Section IV provides a very brief review of what is known about the alternatives in terms of their effects on student learning, then Section V draws together performance and cost information into a mechanism for evaluating alternatives in terms of a simple model of student progress through a school system. The paper concludes with two appendices; the first, as already mentioned, surveys the literature concerning the benefits of education and the second describes an example cost-effectiveness analysis (for elementary education in Indonesia) that was carried out along the lines developed in the text.

II. ALTERNATIVES FOR SCHOOLS

In this section I describe in broad terms the alternatives for schools. I first categorize these alternatives along a number of dimensions and then more specifically discuss the alternatives on the dimension most critical for cost-effectiveness analysis. That dimension concerns the mix of instructional technologies, which has the most direct impact on cost. The set of alternatives actually available to a decision-maker depends, of course, on his budget and Subsection III.C introduces that constraint explicitly.

A. Categorization of Alternatives*

The categories of alternatives that I will use are:

1. degree of physical centralization,
2. mix of instructional methods (including the conventional classroom),
3. amount of time the student spends in school,
4. curriculum mix, and
5. certification, promotion, and retention procedures.

I discuss each of these briefly below, then focus in more detail on those most critical for a cost-effectiveness analysis.

Advances in communication and information storage technology have made possible a considerable decentralization of schools. A first level of decentralization would be to perhaps very small

*A category that will not be discussed here is that of organizational alternatives. In the United States now there is discussion of a number of organizational structures differing from those now in common use; these include performance contracting, community control, and voucher finance.

neighborhood schools. The next level of decentralization would be to the correspondence-school concept where the students receive their lessons at home by audio or video lessons (stored or off the air) and interact with the school system by mail or, for developed countries, through their own terminals. This latter alternative need not preclude gatherings of students for athletics, social occasions, or seminars and discussions. Going in the other direction, one can conceive of much larger school groupings than now exist; one argument in favor of these larger groupings would be to promote social and racial integration.

My own guess is that at the elementary level there are only very limited productivity implications for several fold increases or decreases in the present sizes of schools, though I feel this issue should be further examined. Further, in the rural areas that predominate in developing countries, there may be little choice about the size of schools unless one wishes to consider extensive student transportation and residential schools.

The second category of alternatives concerns the mix of instructional methods. I use the term mix to emphasize that in most departures from the present method of instruction the student will be learning from several instructional techniques during the day. In one mix there might, for example, be 2 hours of ETV in a class of size 60 with one paraprofessional and one older student monitoring, 2 hours of conventional class activity (size 27), 1/2 hour with a teacher in a discussion group with 5 or 6 other students, and 10 minutes at a CAI terminal. Clearly a great many mixes can be built from the basic array of technological and organizational alternatives now available, and we discuss these possibilities in more detail in the following section.

The third dimension of alternatives concerns the amount of time students spend in school--the number of hours per day and the number of days per year. In most countries elementary students spend 4 to 6 hours per day for about 180 days. Using present techniques of instruction, the length of the school year impacts very strongly indeed on costs and it is probably of considerable importance in student learning. There is one further aspect of the "time" question that is much discussed by economists. For students in the higher grade levels, it is argued, there is an opportunity cost to the economy of having the student in school. In estimating the true cost of education one should, then, add in the earnings foregone by students due to their being in school. Schultz [1971] estimates that in the U.S. today the value of earnings foregone by high school students averages somewhat more than $500 per year and for college students somewhat more than $1,200, though much ambiguity surrounds these figures. Schultze further estimates that by about the year 1900 the earnings foregone by primary students had dropped to zero in the U.S.; at present an important use for schools, at this level at any rate, is to provide day-care or "babysitting" facilities. He estimates that approximately half the cost of schooling at the upper levels in developing countries may be in earnings foregone. In the discussion of costs in this paper I will simply note the amount of school time required of students without attempting to assign a value (positive or negative) to it.

The fourth category of alternatives concerns curriculum mix. This has a relatively limited impact on cost so we will not deal with this issue at any length here. It is perhaps worth noting, however, that in one of the very few instances in the United States where performance contracting in schools seems to have improved student performance (over controls) in reading and arithmetic there was a heavy relative emphasis on these subjects in the curriculum -- see Hall and Rapp [1971]. Whatever the appropriateness of this sort of curricular emphasis, its results lend support to the hypothesis that time of exposure to a subject is quite important among the things that schools can influence.

The final category of alternatives concerns promotion, retention, and certification procedures. The range of options here depends to some extent on the state of testing technology. Though testing and certification procedures have only a small direct impact on cost, they have an important indirect impact through their influence on the number of students in the system. We return to this point in Section V where drop-out and promotion rates play a central role in evaluation of the alternatives.

B. Mixes of Instructional Methods

The second dimension of alternatives we discussed in Section II.A concerned the mix of instructional methods, construed to include the present method of instruction that involves a teacher in front of a classroom of students as well as various technologies. I first sketch the conventional alternatives then the technological ones. Section IV then briefly reviews what is known about the performance of the various alternatives in terms of their impact on student achievement.

Conventional Alternatives. The conventional alternatives to the present system fall into several relatively simple categories. These are:

1. Changes in teacher quality (i.e., level of intelligence, education, or experience).
2. Changes in the average number of students per class.
3. Changes in the average number of hours per week and weeks per year the studentspends in school.
4. Changes in the utilization rate of classrooms.

The feasible conventional alternatives can be characterized for any given annual budget for primary education, B, and number of students to be enrolled, N .* Let q be a measure of teacher

*A more general characterization is given in II.C; as the formulation outlined here provides more detail on the conventional alternatives, I include it nonetheless.

quality (for operational simplicity, q may have to be a simple measure such as percent of teachers fully qualified or average educational attainment of teachers) and let $W(q)$ be the average annual wage (for full time work) of teachers when their quality average is q. Let C be the average class size, i.e., the average number of students in a classroom with a teacher and let h be the average number of hours per week a student is in class. Assuming, and this assumption can easily be relaxed, that a full time teacher is in class 36 hours per week, the student to teacher ratio, S, is given by:

$$S = 36C/h \ . \qquad \text{(II.1)}$$

Increasing class size thus increases S, as does decreasing h.

To continue, let U be the average usage rate of classrooms, i.e., the average number of times they are used per day and let P be an imputed annual price for a classroom. Since the available budget was B and the number of students was N, an average of B/N per student per year is the basic cost constraint. Each student consumes $1/S$ or $h/36C$ teachers and $1/UC$ classrooms during the year. Thus the following equation holds as an approximation that includes only the major costs:

$$N[(h/36C)W(q) + P/UC] = B \ . \qquad \text{(II.2)}$$

Equation II.2 summarizes all "conventional" alternatives for the primary system in broadbrush terms. It fails to capture nuances but it specifies, nonetheless, all combinations of teacher quality, class size, hours of class per week, classroom usage rate, and students enrolled that are possible at the prevailing budget, prices, and wages.

If educational research were to the point where planners had functions relating school performance measures to C, q, h, and U, it would become a (relatively) simple mathematical problem to maximize number of greduates per year, say, subject to a budget constraint of

B per year; however, educational research is nowhere near this point. Thus, the approach that will be suggested later is to choose several values of the control variables that differ in different directions from the present values then to estimate the consequences for enrollments and graduates. This gives an idea of the direction in which planners should be moving, even if it fails to say how far they should go. It then allows for comparison with the technological alternatives.

Technological Alternatives. It is somewhat more difficult to categorize the technological alternatives than to categorize the conventional ones. There seem to be two broad dimensions along which the alternatives can be arrayed. The first is alternative technologies and the second is alternative uses for technology. Alternative technologies include:

1. Television.

2. Blackboard or still frame television, i.e., television that presents only alphanumeric characters or line drawings on the one hand or still pictures on the other.

3. Classroom controlled audio-visual media, including tape cassette players.

4. Radio.

5. Computer-assisted and computer-managed instruction (CAI and CMI; with CAI the student is on-line to the computer, with CMI he is off-line).

6. Programmed self-instruction.

Alternative uses for technology include at least the following five possibilities:

1. Enrichment of learning, i.e., provision of occasional lessons or experiences that the classroom teacher cannot easily provide.

2. Total replacement of the teacher in one or more subject areas.

3. Substantial supplementation of the teacher in one or more subject areas.

4. Teacher training.

5. A simultaneous mix of 3 and 4.

Shramm, Coombs, Kahnert, and Lyle [1967] review instances where new media have been used for many of these tasks, as well as for out of school education.

Since six technologies were listed, and five alternative ways of using technology, there are a total of 30 broad "technological alternatives". The next subsection indicates an approach for determining which combinations of these are feasible within a given budget constraint.

C. Alternatives and the Budget

Suppose we are allowed a certain budget, B, per student per year. Any realistic budget completely rules out some alternatives (e.g., 4 hours of CAI per day with 2 hours of private tutoring) while allowing others. The set of alternatives that is actually available is constrained by B and other restrictions.* Here we focus on the budget constraint and assume that B can be divided into five separate components:

$$B = I + S + F + A + T + P \ , \qquad \text{(III.1)}$$

where I = instructional costs,

S = space (or building) costs,

*There are, of course, a great many legal restrictions that vary from country to country but that often put bounds on class size, length of school day, teacher qualifications, etc. In any particular analysis, one must decide on the extent to which these constraints are to be considered immutable.

F = food costs (if applicable)

A = administrative costs, including testing and certification,

T = transportation costs for students, and

P = cost of physical education and recess.

The above symbols refer to costs per student per year. Each of the five categories of alternatives listed in II.A impacts on these costs in different ways. The degree of centralization impacts on S, T, and perhaps A and F . The mix of instructional technologies and the amount of time students are in school determine I . Time in school also affects F, T, and P but probably not A or S since the administrators and schools are there anyway. As mentioned previously, the curriculum mix and certification procedures do not impact too strongly on per-student costs (though they may well affect the number of students at the secondary level).

For the remainder of this discussion I consider alternatives available for primary and secondary schools assuming approximately the present degree of centralization of the system. That simplifies the analysis by enabling us to just examine how time and the mix of instructional technologies affect I , assuming other costs constant. As I accounts for 50% to 80% of school costs in developing countries, this is of central importance. I do feel, however, that examination of the cost impact of a highly decentralized system, i.e., out of school education, should be undertaken.

I turn now to presentation of a framework for arraying the instructional alternatives given any budget level and the assumption that there will be no major change in the degree of centralization of the primary or secondary schools. I ignore as second order the effects of the length of the school year on F, T, and P ; thus the analysis centers on how the mix of instructional technologies and the amount of time the student spends in school are constrained by the instructional budget I .

Assume that we consider n separate "technologies" of instruction.* A teacher with a class of 30 would be one technology, the same teacher with a class of 35 still another, etc. Let f_i be the average fraction of time per day that technology i is used, let h be the average number of hours per day of instruction, let d be the number of days per school year, and let c_i be the cost per student of using technology i for one hour per day. Then

$$I = \sum_{i=1}^{n} dhf_i c_i \ . \qquad \text{(II.3)}$$

The set of points $a = (f_1.....f_i.....f_n; h; d)$ satisfying equation II.3 such that $f_i \geq 0$ for $i = 1,...,n$, $\sum_{i=1}^{n} f_i = 1$, $0 < h < 24$, and $0 < d < 365$ then consists of the set of instructional and temporal alternatives for any one student. If c_i were known for all i one could assign a cost to each alternative and then group the alternatives into equal cost sets for comparison with one another. However, c_i is not only somewhat poorly known but also depends on a variety of factors, including the number of students using the system when fixed costs are important. As an approximation to c_i we assume the following functional form:

$$c_i = \frac{r_i + s_i}{N_{i1}} + \frac{t_i}{N_{i2}} + \frac{p_i}{N_{i3}} \ , \qquad \text{(II.4)}$$

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*The term "technology" is used here in the economists sense to denote any method of instruction. The alternatives here include, then, the conventional alternatives discussed in the preceding subsection.

where N_{i1} = number of students in the classroom using technology i,

N_{i2} = number of students using the delivery system (hardware) of technology i,

N_{i3} = total number of students who use technology i during all its years of use,

r_i = reception cost per class per hour (e.g., an imputed hourly rental of a TV set) of technology i,

t_i = delivery cost per hour of technology i,

p_i = total cost of program preparation, evaluation, and revision, per hour of technology i, and

s_i = cost per hour of teacher or classroom supervisor of technology i.

This formula is only an approximation for a number of reasons including the possibility that r_i and t_i depend on the number of hours of use the classroom hardware and the centralized hardware get, the possibility that annual cost is not strictly proportional to d, and the possibility that one should discount the value of students who use the program later in time. Nonetheless I feel that obtaining reasonable cost estimates within this framework is a useful step and facilitates the structuring of equal cost alternatives for evaluation. Section III deals with costs in more detail.

The central point of this section has been that the appropriate way to formulate the instructional alternatives is through a budget constraint equation. To do this one needs to know (at least approximately) the costs of the alternatives, and equation II.4 represents one mechanism for breaking down the costs. Given costs, equation II.3 then implicitly delineates the mixes of instructional methods feasible given any per student annual instructional budget I. (For a fixed overall school budget the available set clearly expands as one decreases the number of students in school.) The next section discusses cost estimation in more detail then Sections IV and V addresses the effectiveness side of the analysis by suggesting methods for choosing among the obviously vast number of alternatives available within the budget constraint.

III. COST OF ALTERNATIVES

My purpose in this section is to outline a basic framework for discussion of the costs of alternative educational programs. Costs are numbers we assign to outputs to reflect the resources that must be used up to obtain those outputs; a difficulty in education is, then, that it is often difficult to be precise about exactly what the outputs of education are. Is it appropriate to assign costs on a per pupil in average daily attendance basis? on a per graduate basis? on a per unit of measured achievement gain basis? Should the cost be for the average of all students in the system? or the cost of adding one or a few students more? The answer, of course, is that there is no one "correct" way of assigning costs, though there are certainly some incorrect ones. It is the task of the economic analyst working with the educational planner to assign costs in a way that is most illuminating for the particular decision(s) to be made. In deciding among alternative instructional technologies, the appropriate measure might be cost per unit of achievement gain; in deciding among alternative educational strategies, it might be cost per graduate of a fixed quality.

A book soon to be published by P. Coombs and J. Hallak (An Introduction to Educational Cost Analysis) provides a valuable and empirically rich discussion of the problems of analyzing costs of education in developing countries. I will make no effort to summarize that work here. Instead, I will briefly define a few basic concepts of cost analysis and then suggest two new techniques for analyzing the costs of educational technologies that may be of value in decisions concerning whether to use technology. These techniques would serve as supplements and inputs to the more global arraying of alternatives as a function of cost that was presented in equations II.3 and II.4.

A. Basic Concepts of Cost Analysis

In this subsection I will provide informal definitions of two sets of terms that describe costs. The first set of terms is "total cost", "average cost", and "marginal cost"; the second is "capital cost" and "recurrent cost".

As an example, let us consider a six-week summer program designed to provide a specific aspect of in-service training to a group of secondary school teachers. The Ministry of Education is hiring two lecturers and a coordinator plus a large lecture hall for the six-week period; those expenses total an amount X. The Ministry will provide books and room and board for each teacher participating; the cost per teacher for this is Y. The total cost to the Ministry of running the program will, then, be given by $T(N) = X+NY$, where N is the number of teachers participating. $T(N)$ is called a total cost function and, in this case, it assumes the simple form of a fixed cost X plus a variable cost Y times the level of output, i.e., number of teachers trained. The average cost function, $A(N)$, is simply equal to total cost divided by N , i.e., $A(N) = T(N)/N$. Average cost is simply cost per unit of output -- it is often called unit cost -- and it is important to keep in mind that unit cost will vary with N whenever there are fixed costs. In this example $A(N) = (X/N)+Y$.

A third, related cost concept is that of marginal cost, which I will denote here as $M(N)$. $M(N)$ specifies for any given level of output what the incremental cost would be of increasing the output level by one; more explicitly, $M(N) = dT(N)/dN$. In our example, $M(N) = Y$ which is independent of N ; however, if $T(N)$ were non-linear in N -- as will often be the case -- the marginal cost would vary with the level of output. For many decisions, the appropriate cost concept to use is marginal cost because decisions often involve expansion or contraction of a program rather than establishing a new one altogether. If, for example, the Ministry had already committed itself to the summer teacher training program and were trying to decide whether to admit four more students, the appropriate cost to consider is the marginal cost -- 4Y . Appendix B contains applications of total, average, and marginal cost curves to analysis of the cost of instructional radio for Indonesia.

The second set of cost terms to be discussed are the terms "capital cost" and "recurrent cost". A capital cost is, intuitively, a cost incurred to acquire an input that will serve the school system over an extended period of time. A recurrent cost acquires an input that is used up quickly. The distinction here is clearly on a continuum rather than being a dichotomy, and one year is often used as the separating time. Coombs and Hallak (Chapter IX) put the distinction well: "Capital costs are associated with durable educational inputs -- particularly land and site utilities, buildings, furniture and equipment -- which give service for more than a single fiscal year; recurrent costs involve services and supplies that can be consumed within a single accounting year. But the practical line of demarcation must often be drawn arbitrarily and can create confusion in accounting systems."

A common problem in assessing the cost of educational technologies is that there tends to be a high capital cost component and one is then in the position of having to aggregate capital and recurrent costs to be able to delineate alternatives by way of equations II.3 and II.4. One approach is to attempt to express all costs in annual terms. This is straightforward enough for recurrent costs; one simply expresses, say, the teacher's salary on a per annum basis. For a capital cost, one could simply divide the cost by n , the number of years of useful life expected of the equipment, to get an annual cost. This is unsatisfactory for the reason that capital goods are paid for when acquired while much of the cost is assigned by this method to later years and a dollar four years from now is worth less than a dollar now to most societies (even assuming no inflation).* A social discount rate

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*Conceptual and practical problems abound in the area of inter-temporal choice theory and the presentation here is the standard "practical" way out. For background on this, see Sen [1972, Chapter VIII] or Jamison [1970, Section II].

provides a mechanism for comparing dollars spent at different times. If we have a social discount rate, r, the following formula provides a mechanism for computing an annualized cost, $a(r,n)$, as a function of the annual social discount rate r, and the life (in years) of the capital goods, n:

$$a(r,n) = [r(1+r)^n]/[(1+r)^n-1] . \qquad \text{(III.1)}$$

The annualized cost of a capital acquisition is its purchase cost times $a(r,n)$. Kemeny, et. al. (1962, Ch. VI) provide a derivation and discussion of this and related capital accounting formulas.

Use of the above formula allows comparison of costs across time by translating all costs into éffective annual terms. One can then enter these costs into the basic budget constraint of equation II.3 to characterize the alternatives available. This is the approach taken in the example of Indonesian elementary education that is summarized in Appendix B. A shortcoming of an approach that annualizes all costs is that the temporal structure of the costs of the alternatives is lost. In the next subsection I propose an alternative method of analysis that illuminates the time structure of unit costs as seen from different temporal points of view. With the basic cost concepts defined, I now turn directly to that.

B. Unit Costs of Educational Technology Projects

Consider an educational technology* project that costs C_t in year t where C_t includes all expenditures on the project that year whether capital or recurrent. Let N_t be the number of students using the technology in year t and let the social rate of discount be r. The concept I wish to introduce is that of the unit cost from time i

*The concepts developed here are as applicable to non-technology projects.

<u>to time</u> <u>j</u> of the project, which I will denote U_{ij} . Equation III.2 defines this concept formally and following that I illustrate its use with an example.

The following formula gives U_{ij} :

$$U_{ij} = \frac{\sum_{t=i}^{j} C_t / (1+r)^{t-i}}{\sum_{t=i}^{j} N_t / (1+r)^{t-i}} \qquad \text{(III.2)}$$

The basic idea behind this formula is that it sums the total expenditures on the project between years i and j and divides that total by the total number of students benefiting from it in those years. Both the costs and the number of students are discounted back to time i by the social rate of discount r . A decision-maker at time i can in no way influence expenditures or student usage before time i so that costs and benefits incurred up to that time are for his decision irrelevant and are not incorporated into U_{ij} . What U_{ij} tells him is the cost per student of continuing the project through year j , under the assumption that year j will be the final year of the project. By examining how U_{ij} behaves as j varies, the decision-maker can obtain a feel for how long it will take for unit costs to fall to the point of making continuation of the investment worthwhile. When the decision-maker is considering whether the project should be undertaken at all, he should let $i=0$; i.e., he should compute U_{0j} for various values of j .

In order to illustrate the concept of unit cost from i to j I feel a textual example to be appropriate. To simplify matters, I will assume $r=0$; that is, there is no discounting of the future.

With this assumption equation III.2 simplifies to: $U_{ij} = \sum_{t=i}^{j} C_t / \sum_{t=i}^{j} N_t$.

For the example consider a province that wishes to provide one hour per day of ETV to each of the six elementary grades at the schools in the province. Assume that program preparation costs $2,000 for each of the 6 times 150 hours required and that, once taped, the programs last indefinitely. One-third of the programming is prepared each year for the first three years, and one year of programming is prepared before any students use the system. The TV transmitter costs $200,000 and its annual operating and maintenance costs are $20,000; it is installed at the beginning of the first year of broadcasts to students. The remaining cost component is TV receivers and those are assumed to cost $200 each. Approximately 10% of the receivers need replacement each year and power and maintenance for the receivers is assumed to come to 10% of their purchase price each year. By multiple use throughout the day, about 100 students are able to share the cost of a single receiver.

We assume that 50,000 students start viewing after the first year of programming is complete, another 50,000 after the second year, and still another 50,000 after the third year. Thereafter, there are no changes in the size of the audience of 150,000 students. The TV receivers are purchased in the year they are needed. Table III.1 shows the cost components as a function of time, as well as the number of students. From the final two columns of Table III.1 one can compute U_{ij} ; before the project begins it is appropriate to compute U_{0j} , and Table III.2 shows the result of that computation. Column b of Table III.2 shows the total amount (in thousands of dollars) projected to have been spent on the project up to year j ; column c shows the total number of thousands of students projected to have received one hour per day of bTV up to year j . Dividing b by c , then, gives the total cost per student if the project were to end in year j . After 5 years, the cost has dropped to $5 per student per year and after 7 years it has dropped to $3. U_{0j} thus shows to the decision-makers how unit costs decrease as j increases.

Similar computations could be made for U_{1j}, U_{2j}, etc. I do not include those computations here but simply note that for $i \geq 4$

TABLE III.1: Costs and Usage of Hypothetical ETV System

a	b	c	d	e	f	g	h	i
		transmitter cost		receiver costs				
t	programming cost	purchase	use	initial purchase	replacement	maintenance	C_t	N_t
0	600	0	0	0	0	0	600	0
1	600	200	20	100	0	10	930	50
2	600	0	20	100	10	20	750	100
3	0	0	20	100	20	30	170	150
4	0	0	20	0	30	30	80	150
5	0	0	20	0	30	30	80	150
6	0	0	20	0	30	30	80	150
7	0	0	20	0	30	30	80	150
8	0	0	20	0	30	30	80	150

Notes:
1. All costs are expressed in thousands of dollars.
2. N_t is the number of thousands of students receiving one hour daily of instruction by ETV in year t .
3. Column h is the sum of columns b, c, d, e, f, and g.
4. The text describes how the figures in the table were arrived at.

TABLE III.2: Unit Costs Viewed From Year Zero

a	b	c	
j	$\sum_{t=0}^{j} C_t$	$\sum_{t=0}^{j} N_t$	U_{0j} (=b/c)
0	600	0	∞
1	1,530	50	30
2	2,280	150	15
3	2,450	300	8
4	2,530	450	5
5	2,610	600	4
6	2,690	750	4
7	2,770	900	3
8	2,850	1,050	3

Notes: 1. C_t and N_t are from Table III.1.

2. U_{0j} is expressed in dollars per student receiving one hour of ETV per day for a year.

and $j \geq i$, U_{ij} = \$80/150 = \$.52. That is, a decision-maker in year 5 who is deciding whether to continue the project should consider his unit costs to be \$.52 per student per year independently of his time horizon.

In concluding this subsection I should stress that what has been presented is only a way of looking at unit costs, not of ascertaining whether what was paid for would be worth the cost. Nevertheless, as these unit costs enter in a central way into the specification of alternatives given by equation II.3, it is of value to gain insight into how they vary with time and student usage. I will soon make available analyses from the present point of view of the unit costs of the television component of educational reforms in El Salvador and the Ivory Coast.

C. Opportunity Costs of Educational Technology

A still different notion of cost than those discussed so far is the occasionally useful notion of opportunity cost. The opportunity cost of a choice from among a limited set of alternatives is the value to the decision-maker of what he turned down in order to be able to choose what he did. If, for example, the superintendent tells a principal that he can either have two new teachers or a science laboratory and the principal chooses the teachers, the opportunity cost to him of the teachers was a science laboratory.

If a school system's per student expenditure is constrained by equation II.3, then having more of any one thing implies there must be less of something else. For this reason, it may be useful to a decision-maker to see explicitly what these opportunity costs are for certain important categories of alternatives. Since the largest expenditure category for schools is presently teacher salaries, we will examine the opportunity cost of introducing something new (e.g., educational television or radio) under the assumption that it will be "paid" for with less teacher input. Let S be the student to teacher ratio (this is not necessarily the same as class size -- see II.A) before the technology is introduced, and let W be the teacher's annual wage. Let A(N) equal the average annual cost of the technology if N students use it and let I be the increase in class size required to make the post-technology per student instructional cost* equal to R times the pre-technology instructional cost of W/S. As the post-technology instructional cost equals [W+A(N)(S+I)]/ (S+I) the following must hold:

$$W/S = R[W + A(N)\ (S+I)]\ /\ (S+I)\ . \qquad \text{(III.3)}$$

To find the increase in student-to-teacher ratio required to pay for the introduction of the technology, equation III.3 is solved for I giving:

$$I = [SW(I-R) + A(N)S^2R]\ /\ [W-A(N)\ SR]\ . \qquad \text{(III.4)}$$

I represents, then, the opportunity cost of introducing a technology in terms of increased student to teacher ratio. Table B.8 in Appendix B shows values of (S+I)/S for several values of N and R and for a number of ways of introducing radio into the Indonesian elementary education system. While the formula of equation III.4 was developed for expressing the opportunity cost of introducing a technology in terms of student to teacher ratio, similar formulas could be developed between other pairs of inputs. All such formulas would essentially represent ways of analytically evaluating the tradeoffs within equation II.3.

This completes the discussion of basic cost concepts. We now turn to a very brief review of what is known about the effectiveness of alternative instructional techniques.

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*The term instructional cost here denotes the cost of the teacher plus the cost of the instructional technology.

IV. EFFECTIVENESS OF ALTERNATIVE INSTRUCTIONAL TECHNOLOGIES

My purpose in this Section is to give references to surveys that have examined the effectiveness of alternative instructional technologies, including the "technology" of traditional classroom instruction. Patrick Suppes and I are currently preparing a critical survey of the effectiveness of the following technologies: traditional classroom instruction, instructional radio, instructional television, programmed instruction, computer-managed instruction, and computer-assisted instruction. That survey will be made available as soon as it is complete.* Here I will simply mention some of the available evidence concerning traditional instruction, instructional radio, and instructional television.

Much of what we know about the effectiveness of traditional instruction has been obtained from survey data of which the most extensive example is reported in Coleman, et. al. [1966] in their study on Equality of Educational Opportunity. About 20 analyses of the Coleman and similar data are now available, including some studies involving longitudinal data. Several surveys of these studies now exist and the reader is referred to them as a good introduction to the original studies; these surveys are by Guthrie [1970], Katzman [1971, Chapter 2], Averch et. al. [1972], Anderson and Greenberg [1972], and Wells [1972]. A general conclusion that emerges is that school variables explain little of the variance in scholastic achievement, though there are a few such variables -- for example, the teacher's verbal ability -- that do seem consistently related to scholastic performance. Most important from the point of view of educational planning is the finding that class size seems to little affect student performance; since total cost is highly sensitive to class size (or student to teacher ratio), this finding is of considerable practical importance. These survey findings on class size are supported by experimental studies -- see Smith [1972] for a discussion of these issues.

*That survey is now complete. See D. Jamison, P. Suppes, and S. Wells, "The effectiveness of alternative instructional media: A survey", Review of Educational Research, v. 44, 1974, pp. 1-67.

There is by now considerable experience with use of instructional radio, though good evaluational information is difficult to find. A number of recent surveys describe some of the experiences with instructional radio and the reader is referred to those -- Chu and Schramm [1966, Chapter VI], Leslie [1971], Forsythe [1970], and Smith [1972]. If supplemented with appropriate printed material it appears that radio can teach about as well as television for most purposes. The October 1968 issue of the Educational Broadcasting Review contains a bibliography of articles in this area.

The most comprehensive review of studies of the effectiveness of instructional television is that of Chu and Schramm [1966]. Their findings are well known and I will not repeat them here. Generally, television teaches about as well as a well educated classroom teacher. It can teach most subjects and at most grade levels, though its relative performance does seem to vary with these factors.

My general conclusion is that the medium appears to make little difference. What does seem to count for a student with a given set of characteristics is time of exposure to the subject matter and the organization and clarity of presentation. The economic importance of this conclusion concerning effectiveness is obvious.

V. EVALUATION OF ALTERNATIVES

In the preceding three sections I first used the budget as a constraint to delineate the alternatives that educational planners can choose from (Section II), then discussed methods for assessing the cost of the alternatives (Section III) and reviewed evidence concerning their instructional effectiveness (Section IV). My purpose in this Section is to draw together these strands by providing an evaluation model for choosing among the alternatives available, given basic information concerning the cost and effectiveness of the alternatives.

The discussion in this Section concerns the elementary school level in order to be concrete. Similar models could be developed for the secondary level. I should also note that the model developed in this Section is incomplete, theoretically as well as empirically, and the present author and a graduate student are continuing its development.

A. Basic Model*

The basic model of the system uses three standard concepts of educational planning: drop-out rate, progression rate, and repetition rate. These terms are occasionally subject to alternative interpretations, so I will define my usage of them explicitly.

α = drop-out rate = fraction of students in given grade who sometime during, or at the end of a school year leave school for good.

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*The model developed in this subsection is a linear model of flows within a school system and thus has similarities to models developed by Armitage, Smith, and Alper [1969] and Davis [1966].

β = repetition rate = fraction of students in a given grade in a given year who repeat the grade, either the following year or later. (It will be assumed in the model that the number of students in a given year who will repeat any grade after a lag of one or more years equals the number who have left previously and are returning that year.)

γ = progression rate = fraction of students in a given grade who proceed to the next higher grade the following year.

The model makes two assumptions about flows within the system -- the first of which is very natural, the second only an approximation.

Assumption 1. $\alpha + \beta + \gamma = 1$.

Assumption 2. Each of the six elementary grades have the same values of α, β, and γ . This assumption is often a reasonable approximation given inadequacies of existing data; it can easily be relaxed if the data allow more refinement.

This model enables us to predict flows in the system over time. Let $S_t = [s_{1,t}, s_{2,t}, s_{3,t}, s_{4,t}, s_{5,t}, s_{6,t}]$ be the vector giving the number of students in each grade in year t . For example, $s_{3,t}$ is the number of third grade children in year t . Let $A_t = [a_{1,t}, a_{2,t}, a_{3,t}, a_{4,t}, a_{5,t}, a_{6,t}]$ be the number of new students who join the system at each grade level at the beginning of school year t . In view of the way β was defined, the following assumption, about how students join the system, is justified.

Assumption 3. For all t , $a_{2,t} = a_{3,t} = a_{4,t} = a_{5,t} = a_{6,t} = 0$.

That is, new students only enter the first grade.

The following two equations are the basic equations of the system:

$$S_t = S_{t-1} T + A_t \text{ , and} \qquad \text{(V.1)}$$

$$G_t = \gamma s_{6,t} \text{ , where} \qquad \text{(V.2)}$$

G_t = the number of graduates in year t and T is the transition matrix of the system, defined in the following way in terms of β and γ ,

$$T = \begin{bmatrix} \beta & \gamma & 0 & 0 & 0 & 0 \\ 0 & \beta & \gamma & 0 & 0 & 0 \\ 0 & 0 & \beta & \gamma & 0 & 0 \\ 0 & 0 & 0 & \beta & \gamma & 0 \\ 0 & 0 & 0 & 0 & \beta & \gamma \\ 0 & 0 & 0 & 0 & 0 & \beta \end{bmatrix} .$$

The matrix equation V.1 is simply a compressed way of writing a series of equations of the form

$$s_{1,t} = \beta s_{1,t-1} + a_{1,t} ,$$

$$s_{2,t} = \beta s_{2,t-1} + \gamma s_{1,t-1} + a_{2,t} , \quad \text{etc.}$$

The latter equation, for example, states that the number of second grade students in year t is equal to the repetition rate times the number of second grade students in year $t-1$ plus the progression rate times the number of first grade students in year $t-1$ plus the number of new students who enter directly into grade 2 (this last is equal to zero by assumption 3).

In order to use available data to accurately estimate α , β , and γ for a developing country, a few more properties of the system must be characterized. $\underline{N_t}$ will be the total number of students in the system at time t ; $N_t = s_{1,t} + s_{2,t} + s_{3,t} + s_{4,t} + s_{5,t} + s_{6,t}$. The system will be said to have a steady-state input I if I students enter first grade for the first time each year, i.e., $A_{1,t} = I$ for all t . The system will be said to have a steadily growing input at the rate r if $a_{1,t+1} = (1+r) a_{1,t}$, for all t . The fraction of repeaters, to be labeled β^* , is the fraction of students in any one grade who were also in that same grade the preceding year. Notice that the fraction of repeaters is quite a different concept from the repetition rate, though they are obviously related; the exact relation between the two will be described below. The reason fraction of repeaters is introduced is because this variable is easier to observe and measure; the repetition rate may then be inferred from it.

A final concept to be introduced is that of efficiency.* The efficiency, E , of the system relates the number of graduates per year to the number of students in the system, if the system were to have a steady state input. Specifically, $E = 6G_t/N_t$; this is well defined since, if t is moderately large, G_t and N_t are independent of t with steady state input. As the number of graduates per year cannot exceed 1/6 the number of students in the system** -- since the elementary school lasts 6 years -- an efficiency of 1 indicates no drop-outs or repeaters. Even with a true efficiency of 1, however, the apparent value of E could be less than 1 if input is not steady state but is growing. This is because the graduates in year t were first graders six years previously when input was smaller. Thus true efficiency, E , will depend only on β and γ whereas the apparent efficiency will depend on β , γ , and r . For fixed β and γ (and hence fixed E) apparent efficiency decreases as r increases. For example, with 12.8 million students in 1969, and 1.114 million graduates, the Indonesian elementary education system had an apparent efficiency of .515. Since the number of students in the system had been growing at a rate of about 4.2% (r = .042) over the preceding years (Emerson [1968, p. 15]), the true efficiency of the system can be computed to be .590.

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*I use the term "efficiency" here solely in terms of relating inputs to outputs; this usage should not be confused with the common economic usage that relates choice of imputs to their prices.

**It is assumed that a negligibly small fraction of students "skip" grades.

Let me now state some properties of the system. For a steady state input of I per year the following hold:

$$s_{k,t} = \gamma^{k-1} I/(1-\beta)^k , \qquad (V.3)$$

$$\beta* = \beta , \text{ and} \qquad (V.4)$$

$$E = [6\gamma^6/(1-\beta)^6] / \sum_{k=1}^{6} \gamma^{k-1}/(1-\beta)^k . \qquad (V.5)$$

Equation V.3 gives the number of students at each grade level; the result can be established inductively and I will not prove it here. Equation V.4 states that the fraction of repeaters, $\beta*$, is simply equal to β. This can be proved from V.3 in the following way. The fraction of repeaters in a grade will equal the number of students in that grade, $s_{k,t}$, minus the number in the grade who were promoted the previous year from the previous grade, $\gamma s_{k-1, t-1}$, all divided by the number in the grade. That is, $\beta* = [\gamma^{k-1} I/(1-\beta)^k - \gamma^{k-1} I/(1-\beta)^{k-1}] / [\gamma^{k-1} I/(1-\beta)^k]$, and this is easily shown to equal β. Finally, equation V.5 follows directly from the definition of efficiency. The numerator is 6 times the number of graduates and follows from equations V.2 and V.3; the denominator is simply the number of students in the system and follows directly from equation V.3. Table V.1 shows several values of α and β for each of a number of values of E. (The table can as easily be expressed in terms of α and β as in terms of β and γ since $\alpha = 1-\beta-\gamma$.)

The preceding are properties of the system if the input is steady state. If the input is growing, I have been unable to prove similar results; however, the following was checked numerically in a number of cases, and appears to be true:

$$\text{If input is growing at rate } r , \ \beta* = \beta/(1 + r) . \qquad (V.6)$$

This enables us to estimate β from the sometimes more readily available estimates of $\beta*$.

Table V.1: α, β Pairs Consistent with Several Values of E

α	β	E = .80	α	β	E = .65
.01	.16		.05	.18	
.02	.13		.06	.15	
.03	.10		.07	.12	
.04	.06		.08	.09	
.05	.03		.09	.06	

α	β	E = .55	α	β	E = .45
.07	.22		.10	.24	
.08	.19		.12	.18	
.09	.16		.14	.13	
.11	.11		.16	.08	
.13	.05		.18	.02	

The above, then, is the student flow or performance model that underlies the evaluation of the alternatives. In the remainder of Section V I describe how this model is used for this purpose.

B. Evaluation of Alternatives

The model developed in the preceding subsection takes its basic parameters -- α, β, and γ -- as given by the present structure of the school system. Progression from one grade to the next depends, presumably, on the student's convincing the teacher (or system) that he has reached a satisfactory level of educational attainment. Among those who fail to progress, the decision concerning whether the student is allowed to repeat, and whether he chooses to repeat will depend on his performance, his perception of what the school has to offer, and various economic and social factors. For these reasons, changing the effectiveness of instruction in the schools will change α, β, and γ. It would be ideal, of course, if for any instructional alternative a (see discussion immediately following equation II.3) one could assign values to α, β, and γ. It would then be possible to project the output of the school system as a function of time and the level of expenditures assigned to the system. The value of the research on effectiveness of alternative instructional technologies that was overviewed in Section IV is that it gives us some insight into how choice of technique affects flows in the system.* Nevertheless, we are not now in a position to do more than make informed estimates concerning the effects on α, β, and γ of introducing a new mix of instructional techniques.

Given our present state of understanding of the effectiveness of the various instructional technologies, I propose the following

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*Obtaining a clear understanding of these effects is made even more difficult by the fact that there are often changing policies concerning when to let a student progress.

evaluation methodology:

1. Treat as an exogenous parameter the rate of growth of expenditures on the, say, elementary school system. That is, a number of "reasonable" values of this parameter should be selected and the analysis below carried out for each to ascertain how varying the level of expenditure varies the level of outputs.

2. Project the costs of the various techniques of instruction into the future. A reasonable first estimate is that teacher salaries will grow at at least the rate of per capita GNP and that technology costs will remain constant; more refined estimates may be possible.

3. Using equation II.3, identify the combinations of numbers of students in the system and mixes of instructional technologies that are feasible given assumptions 1 and 2 concerning expenditures and costs. From this infinite number of possibilities, select a small number (5 to 20) that are representative of the overall range.

4. Using basic information on effectiveness of the sort mentioned in Section IV, make best estimates of the values of α, β, and γ that will result from each of the representative alternatives selected for examination.

5. For each alternative, insert the appropriate values of α, β, and γ into the model of the preceding subsection and use that model to project the number of graduates as a function of time, the number of dropouts (with various levels of schooling) as a function of time, and the participation rates* of various age groups as a function of time.

6. From the above projections, it will appear that certain alternatives are clearly dominated by others, but that there may be a number of alternatives that cannot be easily decided among. For example alternative i might yield higher levels of numbers of graduates and alternative j higher participation rates; choice

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*This relies on obtaining population projections for the relevant age group.

between them would have to be left to the value judgment of a decision-maker.

7. For the most attractive alternatives identified in Step 6, a sensitivity analysis should be performed to examine the effects of errors in estimating costs or the flow parameters. This sensitivity analysis combined with plans for development and implementation of the promising alternatives should be presented to the decision-maker for his assessment.

A detailed example of the above methodology may be found in Jamison [1971] where alternative conventional and radio technologies were examined for Indonesia. Appendix B of this paper summarizes that analysis; however, the original must be consulted for a detailed presentation of the methods. The purpose of this methodology is to examine the long term consequences of various alternatives for operating the schools. While not specifying any optimum choice of technologies, it does place before a decision-maker much more detailed information concerning the consequences of the more attractive alternatives he has to choose from.

C. Directions for Research

The title of this paper is "Notes on Cost-Effectiveness Analysis..." and I would like to stress that that is all that is intended at the present stage. There are many directions for further research; there will be progress in some of those directions in the remaining research to be done on this project, but much will remain to be done for some time.

On the cost side, it will be valuable to obtain a handbook of instructional technology costs and cost projections. These will often need to be expressed as equations such as II.4 rather than in terms of single numbers. It will also be of value to continue field research on what the costs of various educational technology projects actually have been and are planned to be.

On the effectiveness side there is no substitute for continuing longitudinal hard data analyses like those being done in El Salvador and Mexico. These need to be supplemented by similar analyses for other technologies (as well as for conventional alternatives as Carnoy has been doing in Puerto Rico). They also need to be supplemented by improved information on how the instructional effectiveness of the alternatives, as well as other factors, affect drop-out and repetition rates. This last line of research I consider to be highly important.

The basic evaluation model presented here needs further development. It is important to be able to summarize outcomes in a way or class of ways that would provide more insight to a decision-maker than the simple projections that were recommended here. The drop-out and repetition rates can be treated as being partially decision parameters as well as being partially determined by the choice of technique, and it is important that that possibility be incorporated into the model. A flexible version of the model, capable of working with data of varying degrees of refinement, needs to be put onto a computer in an interactive mode. This would allow planners to get a rapid and solid feel for the implications of the alternatives he is considering.

APPENDIX A: BENEFITS OF EDUCATION

In order to set the context for a cost-effectiveness analysis in education it is of value to restrict the range of output levels to be considered by analyzing the benefits of education. While a detailed survey of those benefits is beyond the scope of this paper, this appendix provides a short summary and references to the literature. Blaug [1970] provides a reasonably complete annotated bibliography and Klees [1972] has drafted a more extensive literature survey.

Education is typically viewed as having several benefits to individuals and, therefore, to society as a whole. Since wages may not reflect the marginal product of labor of a certain educational category the social benefits may differ from those to the individual.* Many benefits of education have defied any form of quantification and are reflected primarily in the high level of demand for education within most countries. In this brief survey I will first list a number of these unquantified benefits then I will briefly review some of the more quantitative results concerning the effect of education on economic growth, on industrial and agricultural productivity, and on wages.

A. Unquantified Benefits

The unquantified benefits include the following. (1) Education has a direct consumption value through its capacity to increase an

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*Wages may differ from marginal product due to distortions in factor markets, a frequent occurence, or due to the existence of "external economies" or "external diseconomies" in education. Economists have typically assumed the existence of external economies, i.e., that there are social benefits to an individual's education that go beyond benefits to the individual himself. See Blaug [1965] or Vaizey [1962].

individual's enjoyment of life. (2) Education has a capacity to improve individual health (and hence, indirectly, economic productivity) by increasing receptiveness to improved nutritional and hygienic practices. (3) Educated individuals tend to be more receptive to birth control information. (4) Educated consumers are more capable of discriminating selection and use of consumer goods leading to less wastage through production of inferior products. The fact that the above benefits of education are not numerically specified in no way implies that they are unimportant. It simply means that an economic planner or decision-maker has less precise knowledge concerning these factors when he combines them with better measured effects to arrive at a final decision concerning what level of resources to devote to the educational sector. Rather more quantitative information is available concerning the effect of education on aggregate economic growth, the earnings of the urban labor force, and on agricultural productivity, and that evidence will be reviewed below. But the reader should be constantly aware that there is considerable inaccuracy in much of the underlying data reported below, and that often the data available is subject to a variety of interpretations.

B. Education and Aggregate Production

In two now classic studies Denison [1962, 1967] attempted to account for economic growth in the United States (The Sources of Economic Growth in the United States and the Alternatives Before Us) and Western Europe (Why Growth Rates Differ). His basic methodology was to specify and to estimate a functional relation (aggregate production function) between output and measures of capital and labor input. Given such a production function one can attempt to account for changes in output from changes in the capital and labor inputs; this attempt left a "residual" of output unaccounted for. However, one can categorize the labor force by level of educational attainment and from an index of labor quality by weighting the number of laborers in each category by the average wage of that category. Changes in this index of labor quality can explain about one third of the residual -- see Griliches and Jorgenson [1967] or Griliches [1970]. A growth in the labor quality index of .8% per year in the United States contributed about .6% per year of growth in GNP in the period 1940-1967.

Theoretically one could divide the value of increased growth in a year by the annual cost of education to obtain a rate of return to education (it would be about 10% in the U.S., by this measure). But for a variety of reasons the specific quantitative result would be of little value. First, this measure could be widely different for developing countries and the data to determine it are unavailable. Second, relative wages do not necessarily reflect the relative marginal products of different types of education, as was pointed out before. Third, the educational system is not the only determinant of the labor quality mix. Even if, for these reasons, the quantitative results are of little practical interest, it is nonetheless significant that these studies consistently indicate that the quality of the labor force accounts for an important amount of economic growth in the developed countries.

C. Education and Worker Productivity

In the preceding comments, I reviewed evidence indicating that one important determinant of aggregate productivity is the average level of education within a country. At this point I will turn to evidence from a much lower level of aggregation; this evidence relates agricultural and industrial productivity in the United States to worker education.

Much of the information concerning the effects of education on manufacturing and agricultural productivity in the United States appears in a series of econometric studies undertaken by Z. Griliches. Many of the important results of these studies are summarized in Table 4 of Griliches [1970], and, with minor modification, that table is reproduced here as Table A.1. For example, in row b of line 1 of the table one sees that a 10% increase in the number of workers would yield a 5.2% increase in output and a 10% increase in educational level would yield a 4.3% increase in output.* The ratios of the coefficients to their standard errors (in parentheses below them) indicate the coefficients to be highly significant. Similar remarks apply to the other three lines in the table. Once again we see that education has a substantial impact on output, here at a much less aggregated level.

While showing a direct link between education and worker productivity, these results again have limited policy implications for developing countries. They are from the United States, they fail to examine costs, and they fail to take into sufficient account the possibility that higher productivity is causing higher levels of education rather than the other way around. Thus even with these disaggregated studies we are unable to come to specific, quantitative estimates of the benefits of education in increasing productivity. Nevertheless, other authors, dealing with problems of developing countries, have reached conclusions that are consistent with Griliches' findings in the United States that higher levels of education lead to higher levels of agricultural productivity. For example, T. Schultz [1964] has stressed the critical role of education in modernizing traditional agriculture but V. L. Griffiths [1968] argues from practical experience that education can be only one of many factors if there is to be success.

D. Education and Urban Wage Level

The studies described above directly examine the effects of average levels of education on output. A much more common method of

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*This follows because the variables in the equation are expressed as logarithms of the original variables.

Table A.1: Education and Skill Variables in Production Function Studies[a,b]

Industry, Unit of Observation, Period and Sample Size		Labor Coefficient	Education or Skill Variable Coefficient	R^2
1. U.S. Agriculture, 68 Regions, 1949	a.	.45		.977
		(.07)		
	b.	.52	.43	.979
		(.08)	(.18)	
2. U.S. Agriculture, 39 "states," 1949-54-59	a.	.43		.980
		(.05)		
	b.	.51	.41	
		(.06)	(.16)	.981
3. U.S. Manufacturing, states and two-digit industries, N = 417, 1958	a.	.67		.547
		(.01)		
	b.	.69	.95	.665
		(.01)	(.07)	
4. U.S. Manufacturing, states and two-digit industries, N = 783, 1954-57-63	a.	.71		.623
		(.01)		
	b.	.75	.96	.757
		(.01)	(.06)	
	c.	.85	.56	.884
		(.01)	(.16)	

[a]All the variables (except for state industry, or time dummy variables) are in the form of logarithms of original values. The numbers in parentheses are the calculated standard errors of the respective coefficients.

Table A.1 (continued)

[b]The source of this table is Griliches [1970], Table 4.

Notes:

1. Dependent variable: sales, home consumption, inventory change, and government payments. Labor: full-time equivalent man-years. "Education" -- average education of the rural farm population weighted by average income by education class-weights for the U.S. as a whole, per man. Other variables included in the regression: livestock inputs, machinery inputs, land, buildings, and other current inputs. All variables (except education) are averaged per commercial farm in a region.

2. Dependent variable: same as in (1) but deflated for price change. Labor: total man-days, with downward adjustments for operators over 65 and unpaid family workers. Education: similar to (1). Other variables: Machinery inputs, Land and buildings, Fertilizer, "Other," and time dummies. All of the variables (except education and the time dummies) are per farm state averages.

3. Dependent variable: Value added per man-hour. Labor: total man-hours. Skill: Occupational mix-annual average income predicted for the particular labor force on the basis of its occupational mix and national average incomes by occupation. Other variable: Capital Services. All variables in per-establishment units.

4. Dependent, labor, and skill variables same as above. Other variables: a. and b. Capital based on estimated gross-book-value of fixed assetts; c. also includes 18 Industry and 20 regional dummy variables.

analysis has been an indirect one that proceeds by assuming that an individual's wages are equal to his marginal productivity. If so, one can assess the economic contribution of education by examining the wage differences between individuals with one level of education and those with another. If one has a cost estimate of the incremental education (including the earnings foregone by the student while in school), and of the wage differences at various points in time over an individual's life, one can compute an internal rate of return* to investment in education. Details of these techniques are described in a very straightforward fashion by Woodhall [1970] and early examples may be found in Hansen [1963] and Blaug [1965]. Most studies are based on urban rather than rural surveys of wages.

Carnoy [1972] has recently drawn from many studies to compile a list of estimated rates of return to primary, secondary, and university education in 27 countries. His list, with detailed references to the original sources, is included as Table A.2. In a forthcoming book G. Psacharopoulos [1972] surveys and critically reviews rate of return data from 32 countries. The average unadjusted social rates of return to education in the less-developed countries surveyed by Carnoy are 17.4% for primary, 15.2% for secondary, and 12.7% for university. Clearly, however, many factors beside education may contribute to the observed fact that individuals with more education have higher incomes. Differing native ability and differing socio-

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*The internal rate of return of an investment is defined in terms of the time streams of costs and benefits resulting from it. Assume that an investment has no benefits or costs after n years and that in year t the cost of the investment is C_t and the benefit B_t. If the interest rate is r per cent per year, the present value of the investment is given by $\sum_{t=0}^{n} (B_t - C_t)/(1 + r)^t$. The value of r that makes the present value zero is the internal rate of return; the higher the internal rate of return, the more rapidly do the investment's benefits repay its costs.

Table A.2: Rates of Return to Schooling*

Social Rates of Return to Schooling, Enrollment Rates, Gross Domestic Product per Capita, and Economic Growth Rates, by Country for Various Years, Primary, Secondary and University Levels of Schooling

Country	(1) Year	(2) Primary Rate of Return	(3) Primary Enroll-ment Rate	(4) Sec. Rate of Return	(5) Sec. Enroll-ment Rate	(6) Univ. Rate of Return	(7) Univ. Enroll-ment Rate	(8) GDP/ Capita	(9) Eco-nomic Growth Rate
United States	1959	-	-	14[a]	82	10[a]	1576	2361	0.4
Canada	1961	-	-	14[a]	56	15[a]	725	1774	0.6
Puerto Rico	1960	21	70	22	46	16	1186	661	4.6
Mexico	1963	25	50	17	12	23	337	374	1.6
Venezuela	1957	82[b]	42	17	10	23	230	730	3.8
Colombia	1965	40	56	24	19	8	307	320	1.4
Chile	1959	12	68	12	23	9[c]	364	365	0.8
Brazil	1962	11	46	17	12	14	182	261	4.0
S. Korea	1967	12	66	9	33	5	760	146	6.6
Israel	1958	16	63	7	36	7	625	704	4.4
India	1960	20	20	13	31	13	281	73	1.8
Malaysia[d]	1967	9	56	12	28	11	142	280	2.8
Phillipines	1966	8	56	21	34	11	1931	250	1.4
Japan	1961	-	-	7	79	6	510	464	5.8
Ghana	1967	18	35	11	34	16	70	233	-0.8
Kenya	1968	22	48	20	6	9	59	118	4.4
Uganda[e]	1965	66	32	50	7	12	19	84	1.4
Zambia	1960	12	28	-	-	-	-	144	4.8

*This Table was compiled by Carnoy [1972] and appears as Table 1 of that paper.

Great Britain	1966	-	-	5	96	8	382	1660	2.4
Germany	1964	-	-	-	-	5	396	1420	3.5
Denmark	1964	-	-	-	-	8	545	1651	4.2
Norway	1966	-	-	7	69	5	375	1831	4.2
Sweden	1967	-	-	10	44	9	647	2500	4.0
Belgium	1967	-	-	-	-	9	384	1777	3.4
Netherlands	1965	-	-	6	91	6	902	1490	3.2
Greece	1964	-	-	3	38	8	374	478	3.8
New Zealand[f]	1966	-	-	20	71	13	1005	1931	3.0

Sources

Columns (1), (2), (4), and (6)--general source: George Psacharapoulos and K. Hinchliffe, "Rates of Return: International Comparison," London School of Economics, Higher Education Research Unit, 1970 (mimeo).

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Ghana: K. Hinchliffe, "Educational Planning Techniques for Developing Countries with Special Reference to Ghana and Nigeria," unpublished M.Phil. dissertation, U. of Leicester, 1969.

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Great Britain: L. Magler and R. Layard, "How Profitable is Engineering Education?" Higher Education Review, Vol. 2, No. 2 (Spring, 1970).

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Sweden: Leif Magnuson, Department of Economics, University of Stockholm (unpublished).

Belgium: W. Desaeyere, "Een Onderwijsmodel voor Belgie, Deel 2," Katholieke Universitaet te Leuven, Centrum voor Economische Studien, 1969 (mimeo).

Netherlands: P. de Wolff and R. Ruiter, De Economie vay he Onderwijs (Gravenhage: Montinus Nijhoff, 1968).

Greece: H. Leibenstein, "Rates of Return to Education in Greece," Harvard University, Economic Development Report No. 94, September, 1967.

New Zealand: B. J. Ogilvy, "Investment in New Zealand Education and its Economic Value, 1951-1966," Unpublished M.Com. dissertation, University of Auckland, 1968.

Column (3): UNESCO, Statistical Yearbook, 1966 and 1967. Enrollment rates taken from Table 2.5 for year five years previous to column (1) year. The rationale for this is that the average person with primary school training is assumed not to enter the labor force for five years after he leaves primary school. So the effect of enrollment rates on rate of return would be lagged by at least five years. The enrollment rate for the column (1) minus 5 years is corrected to a six year length primary school program, so that all ratios represent a six year equivalent primary enrollment as a percentage of 5-14 year-olds in the country. Length of primary school in each country is taken from Table 2.1.

Column (5): Ibid. General secondary education only. The enrollment rate is taken for year three years previous to column (1) year. Enrollment rate is corrected to a four year length secondary school program, so that all ratios represent a four year equivalent secondary enrollment as a percentage of 15-19 year-olds in the country.

Column (7): Ibid. University enrollment is estimated as the number of university students perpopulation 15 years old and older. The enrollment rates are taken from Table 2.10. The correction for population 15 years old and older is based on population data from United Nations, Demographic Yearbook, 1960-1969.

Column (8): George Psacharapoulos, "The Economic Returns to Higher Education in Twenty-five Countries," London School of Economics, Higher Education Unit, 1970, Table 1.

Column (9): United Nations, Statistical Yearbook, 1968. Economic growth rate is taken as the average percentage change in gross domestic product per capita in the period t-5 to t, where t is the year shown in Column (1).

Notes:

a. The rates for the U.S. and Canada as reported are private rates. The rates as shown here have been lowered in accordance with the difference between private and social rates as estimated in W. L. Hansen, "Total and Private Returns to Investment in Schooling," Journal of Political Economy, Vol. 71, No. 2 (April, 1963), pp. 128-40.

b. The 82 percent rate represents the return between illiterates and six years of schooling. Income foregone is assumed to be zero. Both facts imply that the rate is seriously overestimated. It has been omitted from the regression estimates below.

c. The rate as reported in Homberger and Selowsky is 12 percent, but as shown in Carnoy, op. cit., 1967 this is an overestimate. The 9 percent rate is approximate.

d. Rates shown here are underestimates of unadjusted rates, since they have been corrected for non-schooling factors.

e. Rates for Uganda are seriously overestimated, since they are based on differences between average incomes of employees with different amounts of schooling. This assumes that income differences are constant over lifetime. The Ugandan rates are therefore omitted from the regression estimates.

f. Ogilvy uses an alpha-coefficient of 0.5, but he probably overestimates unadjusted rates, since he also uses starting salaries of government employees as his base for estimates.

economic status are perhaps the two most important of these. For this reason it is standard in this literature to apply an "adjustment factor" to the raw rates of return described above. Carnoy uses adjustment factors of .4 for primary, .8 for secondary, and .9 for university for less-developed countries; these lead to adjusted social rates of return of 7%, 12.2%, and 11.4% respectively.

While these rates of return are not dramatically high they do indicate, particularly if consumption benefits are considered, that investment in education has important economic benefits. Carnoy stresses that the computed rates of return are quite sensitive to the estimated costs; it would then follow that reduction in cost through improved efficiency could markedly increase the rate of return to education. It is for this reason that improving efficiency must be a central goal of educational planners.

E. Manpower Planning

In the three preceding subsections I have surveyed attempts to measure the benefits of education, by direct or indirect studies of its past impact on productivity. The term "manpower planning" connotes a rather different way of assessing the benefits of education and, as it is a technique that has been occasionally used by educational planners, I should mention it here. A clear overview of the technique may be found in Parnes [1964] but the technique consists essentially of forecasting into the future the "requirements" the economy will have for each category of educated labor. The benefits of having an educational system accrue to its capacity to meet these requirements.

The manpower forecasting is done by: (1) obtaining estimates of the number of laborers of each level of education required per unit output in each economic sector, (2) forecasting the level of output of each sector at time t, (3) summing across sectors to obtain the total requirement for each educational category of labor, and (4) computing how many new laborers of each educational level must be added to the labor force between now and time t to meet these requirements. It is the task of the educational system to meet these requirements. While the above is an oversimplification of the manpower planning approach, even more sophisticated versions of it tend to share two important flaws. The first is that requirements are set without regard to costs; this could, of course, lead to severe misallocation of resources. Second, this approach fails to allow for a potentially high elasticity of substitution among laborers of varying skill categories; Bowles [1969, Chapter III] argues that this elasticity is, in fact, quite high.

A series of case studies of the usefulness of manpower planning has recently been undertaken -- see Ahamad, Blaug, et. al. [1972] -- and the general conclusion was that they were of little value.

F. Conclusion

In concluding this brief overview of studies of the benefits of education, two central points emerge. First, studies of many types in many countries consistently indicate that education contributes to increased productivity of the labor force. Second, we have only an imprecise estimate of this effect, particularly for developing countries, since only the rate of return studies dealt with data from those countries and those studies have many shortcomings from a policy point of view.

APPENDIX B: AN EXAMPLE COST-EFFECTIVENESS ANALYSIS: ELEMENTARY EDUCATION IN INDONESIA*

In a recent report prepared for UNESCO -- Jamison [1971] -- I examined the potential role of educational technology in alleviating financial and quality problems in elementary education in Indonesia. My purpose in this Appendix is to illustrate the methodological framework of the present paper by summarizing the results of that report. Some of the cost estimates used here have been made out of date by R. Daroesman [1971, 1972] in a recent study of the financing of education in Indonesia. However, the more refined cost estimates she makes available in her papers are, in most cases, rather close to the crude estimates I use and thus many of the results I shall describe are consistent with the numbers she obtains.

The first section of this Appendix provides projections of elementary school graduates and participation rates for various assumptions about the rate of growth of budgets and costs, assuming no change in the structure of the elementary system. The second section outlines alternatives available to Indonesian educational planners and concludes that extensive use of radio appears quite attractive. The final section discusses the cost and probable performance of radio.

A. Projection of Present System

In order to place a discussion of alternatives into perspective,

*The author is indebted to many individuals for assistance and information concerning this Appendix. They include: Mssrs. Kartomo, Setijadi, and Miarso of the Badan Pengembangan Pendidikan (BPP); Mrs. Marcy Avrin, Mrs. Joanne Jamison, and Professor Wilbur Schramm of Stanford University; Mssrs. D. Lacerf and P. Slors of UNESCO; and Mr. David Barlow of BBC. Interpretations and conclusions are, however, the responsibility of the author.

it is useful to project the performance of the present system into the future. Available data can be used to compute an annual drop-out rate of about 10% and an annual repetition rate slightly over 10%; from these numbers I have computed numbers of graduates per year as a function of available budget for elementary schools and per student costs. Assuming an average class size of 35 students, an average teacher salary (in 1968) of Rp. 57,300 per year, an average annual cost of classroom use of Rp. 23,000, and that on the average 1.5 classes use each classroom, the per student annual cost in 1968 was Rp. 2070.* (This compares reasonably well with Daroesman's 1971 survey data estimate of Rp. 2583; much of the difference comes from her estimate of Rp. 66,000 as the annual cost of a teacher.) The total expenditure on elementary education in 1968 is the product of Rp. 2070 and the enrollment of approximately 12,000,000 students -- i.e., about Rp. 24.8 billion. Table B.1 shows the number of graduates as a function of time starting with these 1968 base numbers and assuming no changes in the drop-out and repetition rates. (The growth rate of effective expenditures is

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*All references to rupiahs in this note refer to 1970 rupiahs; there are approximately 340 rupiahs per dollar. Class size and classroom use estimates are based on P. Slors, "Some Bottlenecks in Indonesia's Educational System, with a View on its Future," Unpublished BPP Report, January 1971. Daroesman uses higher estimates -- 40 to 1 for the student to teacher ratio (Part I, p. 84) and more intensive shifting to obtain high classroom utilization (Part I, p. 91).

TABLE B.1: Numbers of Graduates of Elementary School, Present System[a]

Year	Growth Rate of Effective Expenditures[b]			
	-3%	0%	3%	6%
1970	1.130	1.114	1.099	1.085
1974	1.288	1.280	1.270	1.255
1978	1.148	1.280	1.420	1.567
1982	1.019	1.280	1.594	1.971

[a]Figures in the table are expressed in millions.

[b]The rate of growth of effective expenditures is defined to be the rate of growth of real expenditures minus the rate of growth of costs. These numbers are computed by the methods of Section V.A.

the difference between the growth rate of expenditures in real terms less the growth of costs in real terms.) Daroesman estimates that the real growth of elementary teacher salaries (the bulk of costs) will be 3.5%; thus it would take a 6.5% rate of increase in overall expenditures to produce a 3% rate for effective expenditures.

Knowing the level of elementary school enrollment and the number of children aged 7 to 12, one can compute a "gross" participation rate for the system by dividing the second into the first. However, many of the individuals enrolled may actually be over 12 so a more appropriate measure is the number of students enrolled net of the number over 12; this number divided by the total number of children aged 7-12 was defined as the "real" participation rate. The real participation rate can be computed from a knowledge of the drop-out rate, repetition rate, and rate of growth of enroolment; Table B.2 shows projections of the real participation rate as a function of the growth rate of effective expenditures.

TABLE B.2: Real Participation Rates as a Function of Time

Year	Growth Rate of Effective Expenditures[a]			
	-3%	0%	3%	6%
1970	.577	.595	.613	.631
1974	.454	.529	.613	.708
1978	.358	.470	.614	.795
1982	.282	.418	.614	.892

[a]The rate of growth of effective expenditures is defined to be the rate of growth of real expenditures minus the rate of growth of costs.

It is also possible, though slightly more complicated, to iteratively solve for the level of expenditures required to maintain the 1969 real participation rate of about 61% as a function of the rate of growth of real costs; if, for example, real costs increase at a 4% annual rate the real expenditures in 1982 will need to be more than double those for 1971 to simply prevent a decline in the participation rate. It is this rather pessimistic conclusion that leads us to analyze alternatives to the present system.

B. Alternatives to the Present System

If a number of different techniques for providing elementary education exist, then at any given time a certain fraction (perhaps zero) of Indonesian students will be using each technique. An alternative at a point in time is a specification of the fraction of students using each technique at that time, and planning consists of comparing and evaluating various time streams of alternatives. In this section I will analyze a variety of alternatives to the present technique for elementary education and will leave it as understood that not only the techniques presented but any mixes of them are possible alternatives; the basic conventional and technological alternatives to be analyzed are described in Section II.A. The analysis begins by eliminating alternatives that appear clearly undesirable for Indonesia at the present time.

Elimination of Less Desirable Technological Alternatives. Since six technologies were listed in II.A, and five alternative ways of using them, there are a total of thirty broad "technological alternatives". Most of these are unattractive, however, and this subsection sharply reduces this rather extensive list. A basic source of information on the performance of the new media, and to a lesser extent their relative costs, is Learning from Television: What the Research Says by G. Chu and W. Schramm [1968]. Chapter VI of that volume deals with studies of media other than television. Somewhat more detailed cost studies may be found, for past projects, in Schramm, Coombs, Kahner, and Lyle [1967] and in its accompanying 3 volumes of case studies. My analysis at this point will draw heavily on these previous findings.

Chu and Schramm record hundreds of instances where television teaches as well or better than a well trained classroom teacher, in addition to a number of instances where it fails to do as well. Television appears to work relatively better for elementary students than for older ones and there seems to be no doubt that television could effectively teach in the elementary schools of Indonesia. However, television is expensive -- perhaps five times as expensive as radio (Schramm, et. al., p. 131) -- and, except where moving pictures are essential, radio appears to teach about as well. For reason of its much higher cost than radio, I conclude that television is an unviable alternative for primary education in Indonesia at the present time. However, it does appear that transmission costs can be made much lower than they are today -- see Bourett [1971] -- and there may come a time when sufficient funds are available for Indonesian elementary education to include selective use of television. It is also possible that more sophisticated future work on the comparative effectiveness of different media for different tasks will define areas where television is more cost effective.

Blackboard television is a technique under development by Dr. Iskandar Alisjahbana of the Bandung Technological Institute (I.T.B.) with colleagues from Holland. Its major attraction is that its video signal can be transmitted over a voice grade circuit; a disadvantage is that it requires a modification to an ordinary television set that may be costly. As blackboard television is still under development, and its production costs remain uncertain, it cannot be considered an active contender for operational use for the next 4 to 6 years. It appears sufficiently promising, nonetheless, that further development at I.T.B. should be encouraged.

For many purposes, classroom controlled audio-visual media appear potentially attractive. Films teach about as well as television and, though there is less evidence for this, it is reasonable to conjecture that cassette tapes would teach as well as radio. The critical point for comparing these alternatives to broadcast alternatives appears to be the question of economies of scale. Chu and Schramm cite a study of the French Bureau d'Etudes ORTF indicating that over the air transmission of audio was less costly than disc distribution for audiences over about 3000. Presumably the break even number in Indonesia would be considerably less since, due to poorer transportation in Indonesia than in France, each location would require considerably larger inventories of recorded material, which would in turn sharply increase costs. Classroom audio-visual media are discussed at greater length in M. Jamison [1967] and may have a potentially valuable role to play for higher levels of education in urban areas. However, the economies of scale issue would seem to rule them out for mass use at the elementary level.

Fourth on the list of alternative technologies to be considered is radio. In terms of both cost and performance for large audiences radio is attractive. The next section contains more detailed performance information concerning radio as well as cost equations for its use under several sets of assumptions. Chu and Schramm cite a number of studies that indicate radio can teach about as well as television or as a well trained classroom teacher. More recent surveys of the literature concerning instructional radio were referred to in Section IV.

Jamison, Fletcher, Suppes, and Atkinson [1971] present evidence that computer assisted instruction (CAI) is becoming an attractive educational alternative for developed countries, but the cost figures in their paper completely rule out CAI for operational use in Indonesia in the foreseeable future. Computer managed instruction (CMI) is considerably less expensive and Jamison and Ball [1971] have suggested that it is potentially capable of being distributed by satellite at night to quite dispersed and remote areas. Nonetheless, per student annual costs of a minimum of $10 to $15 per subject matter indicate that CMI is not yet to the point where it could be seriously considered for operational use in Indonesia.

In a review of the literature on programmed instruction, Schramm [1964] concludes that programmed self instruction can teach effectively; research available to him at that time was almost entirely conducted in developed countries. Roebuck [1969] reports on an experiment involving programmed instruction that took place in Nigeria. He concludes that programmed texts were successful teaching devices with some students, but that effective usage depended on the presence of a regular teacher and that coordination of students at different points caused considerable administrative difficulty. I have no information available concerning the cost of programmed instruction, although fairly good estimates of part of the cost could be made if the number of pages covered per day were known. I would conclude that programmed instruction is potentially somewhat attractive but probably costly and difficult to imprement on a wide scale. Partially for lack of data and partially because it seems unlikely to be instructionally superior to radio, programmed instruction was not considered further in the UNESCO Report. More consideration should probably be given this possibility, however.

I will now turn to consideration of alternative ways of using the technologies. The first two that were listed -- enrichment and complete replacement of the teacher -- will be considered only briefly. Rather than providing a serious alternative to the present system, enrichment would tend to provide only a minor change, though potentially a somewhat costly one. Complete replacement of the teacher falls at the other end of the scale. The possibility that there would be no need for individuals in the classroom with approximately the level of training of present day primary teachers would seem to be both pedagogically and politically improbable.

Substantial supplementation of the classroom teacher, on the other hand, seems entirely feasible. The medium could take most of the burden of instruction while the teacher would assist individual students, grade papers, and acquire more training herself. For this last reason little real difference exists between this alternative and the last use listed, substantial supplementation plus teacher training. If a medium is used for substantial supplementation, increasing class size or reducing the number of hours in the student's school week would lead to reductions in teacher requirements. This would be true even though the teacher remains in the classroom during all broadcasts, both to supervise the children and for teacher training.

A final use of the medium would be for the sole purpose of improving teacher quality and only through that means influencing student performance. This possibility has been analysed for Indonesia in a BPP study by Miarso that compares use of radio to conventional means for upgrading teachers; he concludes that radio would be considerably less costly.

This completes the initial analysis of the technological alternatives. Radio emerges as the most attractive technology and the most attractive use appears to be for teacher training (to be labeled Radio 1) or for substantial supplementation of the teacher plus teacher training. Four explicit ways of using radio for substantial supplementation were analyzed in my report to UNESCO and these are labeled Radio 2 through Radio 5. Table B.3 describes these 5 uses of radio in more detail; while these uses clearly represent only a few of the logical possibilities, I consider them representative of the major alternatives. Before examining their costs we will return to the conventional alternatives.

Table B.3: Uses for Radio in Primary Education[a]

Label	Description
Radio 1	This alternative is described in detail in Miarso [1970] and involves short term (1 to 3 week) workshops for teacher upgrading. Workshops would use radio and/or recorded audio instruction.
Radio 2	This alternative would leave unchanged all aspects of the present system except that in one subject matter there would be a 20-30 minute daily broadcast at each grade level. The purpose of this broadcast would be to substantially supplement the teacher's presentation in that subject, and to help teach the teacher.
Radio 3	This would be the same as Radio 2 except that there would be daily broadcasts in two subject matters instead of one.
Radio 4	This would be the same as Radio 2 except that the school day would be shortened to four hours for all students to allow for double shifts. The resulting increase in the ratio of the number of students in the system to the number of teachers would help cover the cost of introducing radio.
Radio 5	This would be the same as Radio 4 except that there would be daily broadcasts in two subject matters instead of one.

[a]This table describes the radio alternatives whose cost and performance are analyzed in more detail in the text. Clearly these are not the only ways to use radio; they are, in fact, somewhat conservative in that it is at least conceivable that many more subject matters could be taught. Also, radio could be introduced with much more radical increases (or changes) in average student to teacher ratio than considered here. The purpose of detailed examination of these particular radio alternatives is to ascertain the consequences of promising, and feasible, steps in several different directions.

Less Desirable Conventional Alternatives. The various conventional alternatives appear implicitly in equation II.2. The first variable to consider is that of teacher quality, the importance of which has been stressed by Beeby [1966]. Unfortunately, using conventional means to significantly change the average quality of so large a teaching force as Indonesia's would be enormously costly, take much time (Beeby measures it in generations), and might oblige many teachers to leave their posts unfilled for significant periods. Therefore less significant changes in teacher quality were examined (by Miarso) assuming both conventional retraining and Radio 1.

The second conventional variable is class size. This variable is critically significant due to its impact on cost. A number of studies examining the impact of class size on student performance seem to indicate little impact of these variable on student achievement; see Section IV.

The third conventional variable is number of hours in the student's school week. This, along with class size, determines the average student to teacher ratio and is equally significant in terms of costs. I was able to find less evidence concerning the impact of this variable on performance, but Bennett [1971] argues "... one hard fact to be borne in mind is that very few people in developing rural areas in Africa (and probably elsewhere too) work a full day anyway. This is partly due to tradition but, more significantly, to worms, dysentery and malnutrition. ...there is little objective evidence to show whether much extra is taught in insisting that the underfed children remain in their classrooms six hours a day instead of three or four hours."

A final variable is that of classroom utilization. In order to minimize per student costs it is clearly desirable to increase to the maximum possible the number of hours per day a classroom is used. The feasibility of doing this depends very much on the number of hours per week that classes meet. If the average is four and a half hours per day or less, double shifting is probably possible; otherwise, it might be difficult. As Daroesman [1971] has indicated, classroom utilization is already good in Indonesia -- Slors [1971] indicates 1.5 classes per classroom -- but it would seem desirable to push this closer to 2. The cost implications of this, which are included in the analysis of Radio 4 and Radio 5, are not large but are nonetheless significant, and become more so if class buildings only last 15 or 20 years instead of the sometimes assumed 50.

The above consideration of conventional alternatives suggests the possibility of improving quality through radio while perhaps financing the radio at least partially by higher aggregate student to teacher ratios or rates of classroom usage. We turn to these possibilities in the next section.

C. Cost and Performance of Educational Radio

The preceding section concluded that radio appears to be the most attractive technological alternative for Indonesia at the present time. In this subsection I examine further the cost and probable performance of radio in an Indonesian setting.

Component Costs of Radio. This analysis will deal with five basic components of the cost of providing educational radio -- programming costs, book costs, receiver costs, transmitter costs, and teacher training costs. The purpose of the analysis is not to further refine engineering cost estimates but to combine generally available, though occasionally slightly inaccurate, numbers into a meaningful picture of total cost.

My programming cost estimates come from a recent, highly detailed proposal prepared by Stanford University's Institute for Mathematical Studies in the Social Sciences to the United States Agency for International Development. (By programming cost I mean the total cost of preparing the audio tapes for broadcast plus the cost of writing the accompanying printed material.) The purpose of the proposal was, among other things, to program curriculum for teaching arithmetic by radio in a developing country for grades 1 through 6. The cost was high in order to allow carefully controlled curriculum development based on continual analysis of student response to the instruction. A cost of $75,000 per course year (or $300,000 for the six years) emerges as the best estimate from that proposal, and that is the number I shall use here. It should be stressed, however, that this cost estimate is a very conservative one indeed; Radio Republic Indonesia, for example, currently estimates the cost of its educational programming to be about $60. per hour, or less than $10,000 for a year long course segment. Much of the difference probably lies in the iterative development and evaluation cycle proposed by the Stanford group. In order to assure quality programming for mass usage, the development effort is likely worthwhile -- and it is also a mechanism for gradual implementation. Given this development effort, however, the program will be assumed to last 12 years.

The second component of cost to be considered is that of printed material for the students. For about $.0033 per page, technology now in use in Indonesia can produce books with a 3 year lifetime under moderate student use. New techniques using semiplasticized paper are becoming available that should extend lifetime at this level of usage to 5 or 10 years and perhaps slightly reduce costs. In this report the expected costs are assumed to be $.0025 per page with a 5 year lifetime.* With this estimate, as with all the component cost estimates, the cost equations will also be derived for a pessimistic case assuming 1.5 times these costs and an optimistic case assuming .65 times these costs.

The next cost area is that of receivers. Typical prices for commercial receivers at an electronics store in Jogjakarta in May 1971

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*To give an idea of what is possible in this area, I purchased the two volumes of Paul Samuelson's <u>Collected Scientific Papers</u> in Taipei at a commercial bookstore for $2.50. These were hard bound, very legible, and total over 1800 pages. This is $.0014 per page. An important aspect of the cost of books and printed materials will be that of distributing them to widely scattered rural classrooms, and this point needs further study. I have made allowance for that cost by estimating a somewhat high cost per printed page.

ranged from Rp. 3000 for a Golinda Junior III operating between 40 and 140 meters to Rp. 13,300 for a portable Philips 16RL377 with three separate short wave bands. As it is extremely difficult to separate costs from price when tariffs separate markets from the international economy, I simply use $20 as a representative international price for an excellent battery operated receiver.*

The next cost component is that of transmitters. Detailed cost estimates here must await the decisions concerning medium wave versus short wave versus FM as well as the results of more detailed transmission studies. Nevertheless it is possible to place an approximate upper bound on these costs by using a cost of $5000 for a low power, one man operated transmitter with a radius of approximately 7 miles (11.5 kilometers). About 400 such transmitters are in use in the United States today (in the FM band). Likely it will be possible to economize by placing much larger transmitters in some locations, so this estimate is conservative. My estimates here are further conservative in that each transmitter is only assumed to reach 80% of the students in the schools that it covers and that the average population reached by a transmitter is assumed to be only half what the population density of Java-Madura would indicate. (If the transmission facilities were used for other forms of in-school education or for out of school education, as well as for the primary school uses, then only a fraction of the cost of the transmitter should be charged to elementary school use.) The transmitter is assumed to last 10 years and to have an annual maintenance and operating cost of 10% of its purchase price.

Finally, in order to implement radio, a certain amount of teacher training and orientation will likely be required. This is assumed to cost $10. per teacher ($15. per teacher for training in

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*For approximately $60. it is now possible to purchase a mini-cassette receiver of high quality so that, if desirable, teachers could replay the lessons at times of their own choice. At the other end of the cost range, a pre-set, nontunable receiver would cost much less than $20. Thus the $20. estimate makes allowance for the need for batteries and either maintenance or replacement for defective radios.

two courses), and to be good for ten years since, from an initial point on, the teacher will be learning from the radio.

The above, then, are the basic cost components which will be used in the following analysis. The estimates are believed to be conservative estimates of the state of the art and pessimistic and optimistic variations are also provided. If, however, anyone sharply disagrees with any of the cost assumptions, the following analysis is structured in such a way that he can easily examine the consequences of his own assumptions.

Total, Average, and Marginal Cost Curves. In the following, four different specific alternatives for using radio for substantial supplementation plus teacher training will be analyzed. The first two, Radio 2 and Radio 3 add radio -- for one subject matter and two subject matters, respectively -- with no increase in student to teacher ratio to compensate for the cost. Radio 4 and Radio 5 are alternatives that increase the student to teacher ratio by putting students in grades 3 through 6 on 4 hour shifts without increasing class size. (Most students in grades 1 and 2 are already on shifts.) This also allows for improved classroom utilization. Radio 4 parallels Radio 2 in providing substantial supplementation in a single subject matter; Radio 5 has it for two.* See Table B.3.

All cost equations in this section will be stated in annualized terms. This means that all capital costs, such as programming, must be translated into annual equivalents by the factor $a(r,n) = [r(1+r)^n]/[(1+r)^n-1]$ times the capital cost. Here r reflects the cost of capital and a figure of .15 is used throughout to reflect the high social cost of capital in Indonesia today. n is the expected useful lifetime of the capital outlay; the values of n appeared in the text describing each cost component.

Three cost concepts are used, and these are further described in Section III.A. $T(N)$ is the total annual cost for a way of using

*Presumably Bahasa Indonesian and arithmetic.

radio if N students use the system. T(N) increases as N increases. A(N) is the average annual cost, or unit cost and is defined to equal T(N)/N . Due to the fixed programming costs, A(N) declines to an asymptotic value as N increases.* The third cost concept is that of marginal or incremental annual cost, M(N) ; this is the annual cost per student of adding new students to a system already in operation. M(N) is equal to the derivative of T(N) with respect too N and simply assumes a constant value in the present cost model. In the next paragraph total cost curves for Radio 2 through Radio 5 are presented; average and marginal cost curves follow from them. In all cases 150 pages of printed material per student per year are assumed to be required for each course (i.e., 150 pages per year are required for Radio 2 and Radio 4, 300 pages per year are required for Radio 3 and Radio 5.

The total cost of Radio 2 will be designated $T_2(N)$, for Radio 3, $T_3(N)$, etc. These equations are expressed in terms of the following variables, whose values were justified in the text.

T = transmitter cost = U.S. $5000.
R = receiver cost = U.S. $20.
B = book cost = U.S. $.0025 per page.
P = programming cost = U.S. $75,000 per course year.
W = teacher workshop cost = $10. for Radio 2 and 4, but $15. for Radio 3 and 5.

The total cost curves follow:

$$T_2(N) = a(.15,12)6P + a(.15,5)150NB + a(.15,5)NR/70 + [.1+a(.15,10)]\,NT/9375 + a(.15,10)NW/35 \quad \text{(B.1)}$$

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*The UNESCO Report upon which the Appendix is based was prepared prior to the development of the unit cost representations described in Section III. While not incorrect, the presentation of costs in the annualized terms used in this Appendix is, I now feel, less illuminating to a decision-maker than the other would be.

$$T_3(N) = a(.15,12)12P + a(.15,5)300NB + a(.15,5)NR + [.1+a(.15,10)]NT/9375 + a(.15,10)NW/35 . \quad (B.2)$$

$$T_4(N) = a(.15,12)6P + a(.15,5)150NB + a(.15,5)NR/105 + [.1+a(.15,10)] NT/9375 + a(.15,10)NW/52.5 . \quad (B.3)$$

$$T_5(N) = a(.15,12)12P + a(.15,5)300 NB + a(.15,5)NR/52.5 + [.1+a(.15,10)] NT/9375 + a(.15,10)NW/52.5 . \quad (B.4)$$

A few notes are in order concerning the construction of these formulae. The source of programming and book costs is fairly clear. For Radio 2, two classes share a receiver; for Radio 3, one class; for Radio 4, three classes (possible because of shifting); for Radio 5, one and a half classes. The .1 appearing in the transmitter cost term is to allow for operations and maintenance. The transmitter term is the same for all uses, though transmitter utilization would vary from 3 hours per day with Radio 2 to 6 or more hours per day for Radio 5, the exact number depending on how the shifting is done. Radio 2 thus leaves more free air time for out of school education, entertainment, or other formal educational uses. (It is in keeping with this report's policy of conservative cost estimation that the full transmitter cost is charged to the primary school use.)

Table B.4 shows expected, pessimistic, and optimistic total cost equations for the each radio alternative. Expected costs are computed from the values of T, R, B, P, and W shown above; pessimistic costs equal 1.5 times expected costs; optimistic costs equal .65 times expected costs. The unit cost equations and values of the marginal costs are shown in tables B.5 and B.6.

The costs shown in Tables B.4 to B.6 are all effective annual costs in which capital costs are spread over their useful lifetime with an assumed social cost of capital of 15%. While the annualized costs give a more accurate representation of the "true" annual costs, it is also valuable to show actual expenditures required, by category and by year. The information in equations B.1 to B.4, and in the cost

Table B.4: Total Annual Cost Formulas[a,b]

	Programming		Printed Material		Receiver		Transmitter		Teacher Training
Radio 2									
Expected	28,225,530	+	38.035N	+	28.979N	+	54.264N	+	19.356N
Pessimistic	42,338,300	+	57.053N	+	43.469N	+	81.397N	+	29.034N
Optimistic	18,346,590	+	24.723N	+	18.837N	+	35.272N	+	12.581N
Radio 3									
Expected	56,451,130	+	76.071N	+	57.959N	+	54.264N	+	29.034N
Pessimistic	84,676,700	+	114.106N	+	86.938N	+	81.397N	+	43.551N
Optimistic	36,693,230	+	49.446N	+	37.673N	+	35.272N	+	18.872N
Radio 4									
Expected	28,225,530	+	38.035N	+	19.320N	+	54.264N	+	12.904N
Pessimistic	42,338,300	+	57.053N	+	28.979N	+	81.397N	+	19.356N
Optimistic	18,346,590	+	24.723N	+	12.558N	+	35.272N	+	8.388N
Radio 5									
Expected	56,451,150	+	76.071N	+	38.639N	+	54.264N	+	19.356N
Pessimistic	84,676,720	+	114.106N	+	57.959N	+	81.397N	+	29.034N
Optimistic	36,693,230	+	49.446N	+	25.115N	+	35.272N	+	12.581N

[a]Costs are in current rupiahs, converted from dollars at Rp. 340 per US dollar.

[b]For any value of N, the number of students in all grades using the system, the sum across the row shows the total annual cost of providing radio for all the students. Capital costs are converted to annual costs on the basis of their expected lifetime and a social cost of capital of 15%.

Table B.5: Average Annual Cost Formulas[a]

Radio 2			
Expected	28,225,530/N	+	140.634
Pessimistic	42,338,300/N	+	210.953
Optimistic	27,519,880/N	+	91.413
Radio 3			
Expected	56,451,130/N	+	217.328
Pessimistic	84,676,700/N	+	325.992
Optimistic	55,039,840/N	+	141.263
Radio 4			
Expected	28,225,530/N	+	124.523
Pessimistic	42,338,300/N	+	186.785
Optimistic	27,519,880/N	+	80.941
Radio 5			
Expected	56,451,150/N	+	188.330
Pessimistic	84,676,720/N	+	282.496
Optimistic	55,039,850/N	+	122.414

[a]Average annual cost is total annual cost, Table 3.1, divided by the number of students, N. These are commonly called unit costs. Costs are in rupiahs.

Table B.6: Annual Marginal Cost[a]

	Radio 2	Radio 3	Radio 4	Radio 5
Expected	140.634	217.328	124.523	188.330
Pessimistic	210.953	325.992	186.785	282.496
Optimistic	91.413	141.263	80.941	122.414

[a]These represent the average annual cost per student of adding a fairly large group of students to the system in a location where there is no transmitter available. For either small or large groups of students, adding to the system in a location with a transmitter would cost about Rp. 54 less than indicated in the table--see column 4 of Table 3.1.

figures preceding these equations is sufficient to determine these costs, if a specific pattern of implementation is assumed. The costs per year of implementing Radio 5 are shown in Table B.7, under the assumption that the decision to implement follows evaluation of the success of two years of program and curriculum development. The rate of implementation is assumed to be one million students per year for ten years; more rapid implementation would, of course, increase costs in early years but decrease them later. Similar time streams of costs can easily be constructed for the other radio alternatives, or for other assumptions about rate of implementation.

Opportunity Cost of Radio. If one wishes to introduce radio into the system without increasing per student instructional costs (i.e., costs of teacher plus radio) by more than a factor of R , one may have to increase the student to teacher ratio in compensation. It is important to know by how much the student to teacher ratio increases, and this can be computed in a straightforward way using the methods of Section III. Let W be a teacher annual wage and S be the student to teacher ratio before introduction of technology. $A(N)$ is, as before, the average annual cost of the technology and we let I be the increase in class size required to make the post-technology per student instructional cost equal R times the pre-technology instructional cost per student of Rp. W/S . The post-technology instructional cost equals $[W + A(N)(S+I)]/(S+I)$; we thus have:

$$W/S = R[W + A(N)\ (S+I)]\ /\ (S+I)\ . \qquad (B.5)$$

To find the required increase in class size, equation 4.5 is solved for I giving:

$$I = [SW(1-R) + R\ A(N)S^2]\ /\ (W - R\ A(N)S)\ . \qquad (B.6)$$

Table B.8 shows $(S+I)/S$, the ratio of post- to pre-technology class size for several values of N . It assumes that $S = 35$ and

Table B.7: Cost Per Year For Implementation of Radio 5[a,b]

			Cost Element				
Year	Programming[c]	Transmitter Purchase	Transmitter Operations[d]	Receivers[e]	Printed Material[e]	Teacher Workshop	TOTAL
1	225	0	0	0	0	0	225
2	225	0	0	0	0	0	225
3	225	525	53	380	750	285	2218
4	225	525	105	380	750	285	2270
5	0	525	158	380	750	285	2098
6	0	525	210	380	750	285	2150
7	0	525	263	380	750	285	2203
8	0	525	315	760	1500	285	3275
9	0	525	368	760	1500	285	3328
10	0	525	420	760	1500	285	3380
11	0	525	463	760	1500	285	3423
12	0	525	525	760	1500	285	3485

[a]Costs are expressed in thousands of US $.

[b]The pattern of implementation whose costs are shown in the table assumes an initial two year period of programming and curriculum development at the end of which time a decision would be made concerning implementation. The implementation rate shown is for one million new students to be receiving radio each year from year three on, for ten years. Thus, for example, in year six there would be four million students using the system. Numbers in the table are based on equation 4.4 and the cost figures shown preceeding the equation 4.1.

[c]The programming and curriculum development costs are based on Radio 5's requirement of 12 year long courses at $75,000 per course, with development spread over four years.

Table B.7 Continued

[d]Transmitter operations and maintenance were assumed to cost annually 10% of the assumed purchase price of the transmitter. The total amount spent for this steadily increases through year 12 as more transmitters are installed. Again, it should be stressed that both the transmitter purchase and operations costs in this table are almost surely overestimates; a detailed transmission would improve on the pattern of transmitter use implied in this report.

[e]Annual expenditures on receivers and printed material double in year 8 since, due to the assumed five year lifetime of these item, those installed in year three must be replaced in addition to the new installations.

that W = Rp. 57,300 . When R equals one the per student instructional cost after technology is, of course, the same as it was before. It is interesting to note that if N is even moderately large, the opportunity cost of Radio 5 is only an increase of about five in the student to teacher ratio -- from 35 to about 40. This increase is more than covered in Radio 5 by the shortened school day, without requiring larger class sizes. Table B.8 also gives an idea of the effect of scale of operation on costs. Table B.5 shows how scale affects unit costs in rupiahs while Table B.8 shows the effect in terms of required changes in the student to teacher ratio. For Radio 5, usage by 500,000 to 1,000,000 students per year makes fixed cost per student only a fraction of variable costs.

Probable Performance of Radio. From the surveys mentioned in Section IV, I feel it reasonable to conclude from the literature that radio can teach about as well as a well trained classroom teacher if radio is properly programmed. In computing the effect of using radio, this capability is assumed to reflect itself in reduced dropout and repetition rates.* In my report to UNESCO the impact of radio on graduation and participation levels was computed under the assumption (conservative, I felt) that only one-third of the effect reported in El Salvador would obtain in Indonesia.

To compute the effect of introducing radio, the level of effective expenditures was assumed to increase at a rate of 3% per year and the marginal cost of the radio alternative was added to the present per student cost of 2070.** The fixed costs of program preparation were

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*When TV was introduced in El Salvador, E. McAnamy, J. Mayo and R. Hornik [1970] report that 7th grade dropout rates went from .133 to .09; the reduction in repetition rate was correspondingly greater. More recent information on this may be found in Hornik, et. al. [1972, Ch. 4].

**In the case of Radio 4 and Radio 5, the cost of providing radio must be added to a lower base cost of classroom instruction due to the shortened school day and increased classroom usage. The average value of S is assumed to rise to 42.5 with either of these, and classroom usage is assumed to rise to two classes per classroom.

Table B.8: Increase in Student to Teacher Ratio Required to Finance Radio[a]

Students in System[b]	Radio 2 R 1.0	Radio 2 R 1.15	Radio 3 R 1.0	Radio 3 R 1.15	Radio 4 R 1.0	Radio 4 R 1.15	Radio 5 R 1.0	Radio 5 R 1.15
.25	1.182	1.033	1.370	1.233	1.169	1.019	1.338	1.198
.50	1.137	.986	1.252	1.106	1.124	.973	1.225	1.077
1.0	1.115	.964	1.200	1.052	1.103	.952	1.175	1.026
2.0	1.104	.954	1.176	1.027	1.092	.942	1.152	1.002
5.0	1.098	.947	1.162	1.012	1.086	.935	1.139	.988
10.0	1.095	.945	1.157	1.007	1.084	.933	1.134	.984

[a]Entries in the table show the ratio of the student to teacher ratio after technology is introduced to what it is now (assumed to be 35), if the total instructional (teacher + medium) cost is not to increase by more than a factor of R. Clearly this entry must be greater than 1 if R = 1, but it may be less than 1 (decrease in student to teacher ratio) when R = 1.15.

[b]This refers to the number of millions of students in the primary school system who are using radio.

substracted from the available budget, and the methods of Section V were used to compute the number of graduates per year and real participation rates. Under these assumptions all the radio alternatives perform better in terms of graduates and real participation rates than does the present system. Radio 5 does the best, about 25% better than the conventional in terms of graduates and 20% better in terms of participation rate.* These differences are sufficiently large, and were computed under sufficiently conservative assumptions to conclude that the case for use of radio in Indonesia's elementary schools appears quite strong. Before commitment to operational use of radio, however, extensive tests of its effectiveness within Indonesia should be carried out. These issues are more extensively discussed in Jamison [1971].

D. Conclusion

In this Appendix I have provided an extended example to both illustrate the methodology developed in the text and, hopefully, to show that that methodology has practical value for educational planners. It cannot be stressed too strongly, however, that both the methodology and its applications need further development and testing.

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*For example, under the assumption of a 3% rate of growth of effective expenditures, the projected 1982 real participation rate using radio 5 is 73.6%; the projected 1982 number of graduates is 2.01 million. This contrasts with numbers of 61.4% and 1.59 million for the present system.

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