THE BENEFIT-COST RATIO IN RESOURCE DEVELOPMENT PLANNING

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The stimulus for this article was an observation that resource development in the United States is of a lumpy or whole project-by-project character. We seem to have looked at resource development proposals in isolation from other worthwhile activities and to have been preoccupied with the magnitude of "benefit-cost ratios" in evaluating and comparing individual resource development activities, projects, or programs. Unless properly interpreted, however, such ratios can mislead planners and legislators to invest capital and other inputs in a way that leads to a less than fully efficient pattern of resource development, even where the objective is only to maximize quantifiable monetary benefits. Accordingly, this analysis examines the "benefit-cost ratio" in the context of an income-producing efficiency objective and elementary production theory. Such other currently emphasized objectives as environmental quality improvement are treated implicitly, though not within a multiobjective framework. For a more complete treatment of these see Miller and Holloway [9] who have illustrated an application of multiobjective resource planning principles recently issued by the Water Resources Council [15]. Other particular papers and reports dealing with multiobjective resource development planning are [3, 4, 5, 7, 9, 13 and 14].

To begin with, the mathematical ratio of total development benefits over total costs is first interpreted in economic terms. Legitimate uses of the ratio as a choice criterion are then reviewed for cases where the ratio does not vary with the scale of an individual development project or activity, where it varies with project scale, and where a series of development alternatives are under consideration. Relations between planning on the basis of benefit-cost ratios versus examining comparative rates of return on investment capital as such are discussed briefly. Some concluding remarks deal with the question of supporting or not supporting additional research aimed at improving techniques of economic analysis as applied to resource development.

UNDERLYING DEFINITIONS AND CONCEPTS

The benefit-cost ratio, as commonly used in resource development planning, can be defined as dollars of total capitalized benefits divided by dollars of total capitalized cost, where capitalized costs and benefits can be expressed either as discounted (present value) or recurring (annual) amounts. Program, project, and activity costs include expenditures required to obtain the use of productive factors employed in realizing benefits. Such expenditures can be considered as the values foregone by not incurring them for other economic activities. Land, labor, capital, and management are principal classes of productive factors usually involved. In general, all construction, operation, and maintenance expenses can be associated with one or another of these classes of factors. Outlays may take the form of purchase prices or rent for land, wages for labor, and interest on capital investment.

Monetary benefits represent market or imputed values of goods or services rendered by a development through employment of the productive factors mentioned above. Benefits are computed by multiplying physical quantities of goods or services, such as kilowatt-hours of electric power or acre-feet of storage capacity in reservoirs, by their estimated unit values. The unit value of power is usually taken as its selling price or marketable value per kilowatt-hour. The unit value of storage capacity, however, depends on the particular purposes for which the capacity is utilized; that is, whether it is used for recreation, power generation, flood control or irrigation.

The benefit-cost ratio can be calculated at any

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level of aggregation. It can refer to programs or projects in total, project activities, individual beneficiaries or participants, or project subareas. The main requirement in this regard is that costs and benefits be accurately associated. Net benefits are total benefits less total costs. Consequently, the ratio of net benefits over total costs (or dollars of "profit" for each dollar invested) is computed by subtracting 1.00 from the corresponding gross ratio of benefits over costs, and a value greater than zero is taken to justify the expenditure. However, the gross ratio is almost always the one presented and discussed in evaluation reports, and a value for it of unity is commonly regarded as the threshold value of justification. A recognition that development activities, projects or programs can each have a varying scale is essential in interpreting the subsequent discussion.

RESTRICTIONS ON INTERPRETATION OF THE RATIO

By definition, the popularly used benefit-cost ratio is an average. Average relations are properly utilized in allocating scarce resources (including money) if they are synonymous with marginal relations. Therefore, the benefit-cost ratio as popularly computed in resource evaluations is an appropriate criterion for deciding how to allocate resources to a project provided it satisfies the following condition, called Condition X: *The ratio does not change with the amount of money represented by the total costs assigned to a particular program, project, or activity.*

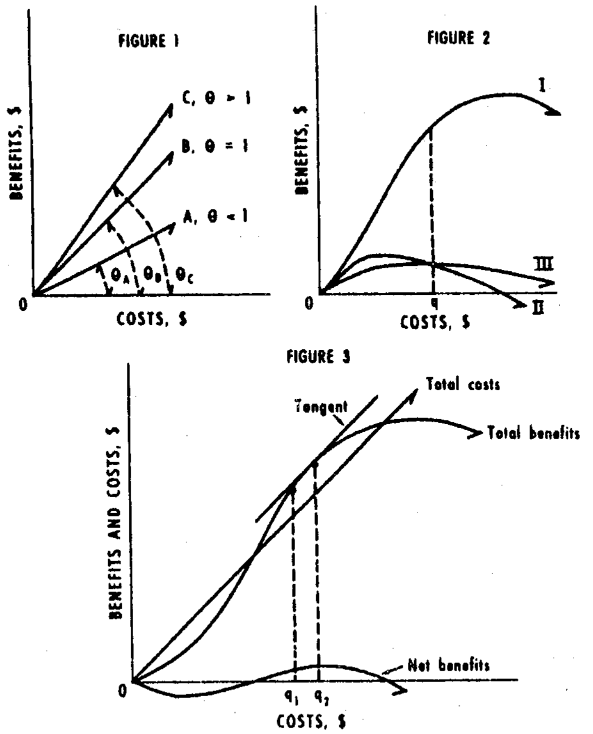
Condition X Satisfied

In Figure 1 there is a straight-line relation between total costs and total benefits. Slopes of the three benefit lines A, B, and C do not change with costs, so they denote ratios of marginal changes in benefits to marginal changes in cost as well as ratios of total benefits divided by total costs.

Condition X Not Satisfied

In Figure 2 there is not a straight-line relation between total costs and total benefits. Line II, as the marginal benefit-cost ratio and the plotted slope of line I, changes as costs change and so is not the same as average benefit or the conventionally figured benefit-cost ratio. The latter is shown as line III. Marginal and average relations (lines II and III) coincide at one point in Figure 2–where costs total q dollars. At this point, the benefit-cost ratio is a maximum but net benefits are definitely not maximum. The case shown in Figure 2 can be expected much more frequently than the case illustrated by Figure 1.

Where benefit-cost relationships are not of a straight-line nature, programs, projects, or activities



FIGURES 1, 2, and 3. SCHEMATIC BENEFIT-COST RELATIONS

can be compared validly by the benefit-cost ratio criterion alone only if the scale is fixed at the same cost level among all programs, projects, or activities. Example:

Project	Gross Benefits	Total Costs	Net Benefits	B/C Ratio
1	$3,000	$2,000	$1,000	1.50
2	7,500	6,000	1,500	1.25
3	6,600	6,000	600	1.10

Costs of projects 1 and 2 are not equal in this example. Net benefits are greater in project 2, although its benefit-cost ratio is less than that of project 1. Moreover, there is no *a priori* justification for inferring that the ratios for either projects 1 or 2 would remain the same if costs were not as shown. Because costs for projects 2 and 3 are equal, their B/C ratios can be compared. Project 2 is clearly preferable to project 3 for the expenditure of $6,000, as it is 2.5 times as efficient as project 3 in yielding net benefits.

USEFULNESS OF THE BENEFIT-COST RATIO

The examples illustrated by Figures 1 and 2 show how the benefit-cost ratio can be used as an efficiency standard if Condition X is met or is not met. The general guide is to determine what the same cost will do in different programs, projects, or activities, without assuming, however, that such comparisons will remain valid if costs are either increased or decreased in any of the programs, projects, or activities. The essential point is that proper use of the benefit-cost ratio in incurring costs or appraising projects, while still based on the relation between costs and benefits, allows for any changes in the relation as costs are changed. Some different uses are explained next. The discussion hinges on whether the gross benefit-cost functions are linear or are not linear.

Linear Functions

Three possible subcases are described, based on constant magnitudes of the function slope.

A. If the benefit-cost ratio is less than unity, money will be lost, whatever benefits are received, and losses will increase proportionately with costs. Refer to line A in Figure 1, where $\tan\ \theta < 1$. A broad decision rule here would be that, unless more-than-compensating net intangible values can be realized, no expenditure is justified.

B. If the benefit-cost ratio is equal to unity, net benefits will be zero regardless of the total benefits received. Refer to line B in Figure 1, where $\tan\ \theta = 1$. The decision rule here is that the expenditure is a matter of indifference unless the existence of associated net intangible values or net intangible losses was established, and the decision was modified accordingly.

C, If the benefit-cost ratio exceeds unity, net benefits will increase proportionately with cost. Refer to line C in Figure 1, where $\tan\ \theta > 1$. The broad decision rule in this case is that expenditure is essentially limited only by more lucrative alternatives and the cost that could be incurred. However, associated intangible benefits and costs should be considered here too, as the existence of associated net intangible losses considered significant by the decision-makers could limit or at least qualify their judgment of the desirability of the activity.

Nonlinear Functions

Determining justified cost if the benefit-cost function is not linear, or if the benefit-cost ratio is not constant and so is in contradiction to Condition X, is discussed with reference to whether the scale of only one alternative (Case D) or the scales of more than one alternative (Case E) are being considered. The discussion assumes that associated intangible values or losses may be involved in either case and could modify the decisions implied.

Case D. If the appropriate scale of only one project or activity is under consideration, the economic rule is to incur costs to the point where added total cost is equal to added total benefit obtained. Expected net benefits are a maximum by so doing. Referring to Figure 3, the optimum cost to incur is shown as q_2 dollars. The amount q_2 is identified by drawing to the gross benefits function a tangent that parallels the total cost function, and then dropping a perpendicular to the horizontal or cost axis from the tangency point. The total cost function will be at 45 degrees from the horizontal, as in Figure 3, if scales of the horizontal and vertical axes are drawn the same.

The hypothetical data given in Table 1 elaborate these points and approximate the relations drawn in Figure 3. Column 2 in the table shows gross benefits, denoted by the upper curve in the figure. The benefit-cost ratios of Column 3 are not plotted in Figure 3 but would have the general form of line III in Figure 2. Column 4 in the table represents the net benefit curve of Figure 3. Columns 5 and 6, respectively, indicate successive incremental or marginal changes in gross benefits and total costs.

Net benefits of \$9.60 in Table 1 approximate the highest point of the net benefit curve in Figure 3. The precise maximum is slightly more than this, as a comparison of marginal benefits and costs (columns 5 and 6) will indicate. Net benefits will begin to decline after costs and benefits are found to be increasing at the same rate (at just under q_2), not at q_1 where the ratio of benefits to costs is greatest. Incurring costs of more than \$12 or q_1 where the benefit-cost ratio is greatest is clearly justified, because marginal or incremental benefits of \$4.40 at q_1 are more than twice the \$2 of marginal or incremental cost.

Case E. If the appropriate scales of a series of projects are under consideration, the general rule is that net benefits will be maximized if costs are incurred among the projects so that marginal net benefits are the same in all projects undertaken, and would not be greater if the equivalent cost were to be devoted to any omitted project. The rule fits those situations where resources may be sufficient to undertake each project at scale q_2, thus getting maximum net benefits in each one by pushing its marginal net benefits to zero. But the rule also recognizes that, owing to capital, engineering, or perhaps political or institutional constraints, it may not be possible to incur the cost that would push to zero the rate of increase in net benefits for an entire series of projects. Moreover, some projects may be omitted entirely if budgets are tight, because marginal net benefits for such projects, even though they may be quite substantial at low-cost levels, may be exceeded by those for other projects at equivalent cost levels.

TABLE 1. HYPOTHETICAL SCHEDULE OF BENEFITS AND COSTS

(1) Total cost	(2) Total benefits	(3) Ratio	(4) Net benefits	(5) Benefits	(6) Costs
		(2)/(1)	(2) – (1)		
$ 0	$ 0		$ 0	$ 0	$ 0
2	1.00	0.50	–1.00	1.00	2
4	3.00	0.75	–1.00	2.00	2
6	6.60	1.10	0.60	3.60	2
8	11.60	1.45	3.60	5.00	2
10	16.00	1.60	6.00	4.40	2
12, q_1	20.40	1.70	8.40	4.40	2
14	23.10	1.65	9.10	2.70	2
16	25.60	1.60	9.60	2.40	2
17, q_2	26.60	1.56	9.60	1.00	1
18	27.00	1.50	9.00	0.40	1
20	25.00	1.25	5.00	–2.00	2

The general rule for Case E can be validated with principles from basic economic theory. Carlson's text [1] is excellent for this purpose. The procedure is also covered by many other authors, often under the theory of price descrimination. Figure 4, as taken from reference [11], illustrates a practical planning problem of discriminately deciding the optimum total and separable capacities of a dual-purpose reservoir designed to serve irrigation (i) and municipal-industrial water demands (m). The curves B_i and B_m in Figure 4 denote gross benefits obtained by storing water for each purpose in relation to respective separable allocations of any total capacity that might be planned. Incremental benefits for each purpose are the derivatives of their respective gross benefits and are denoted by B_i' and B_m' in the lower section of the diagram. Total incremental benefits B_t' stemming from either or both purposes are synonymous with B_m' at capacities under S_x. Thereafter, B_t' is composited from B_i' and B_m' by horizontal adding. The total benefit curve B_t in the upper section is not the sum of B_i and B_m. It is the compound integral of B_t'. Total cost as related to total capacity is given by C_t and marginal cost is C_t'. Corresponding aggregate net benefits as total benefits less costs are N_t.

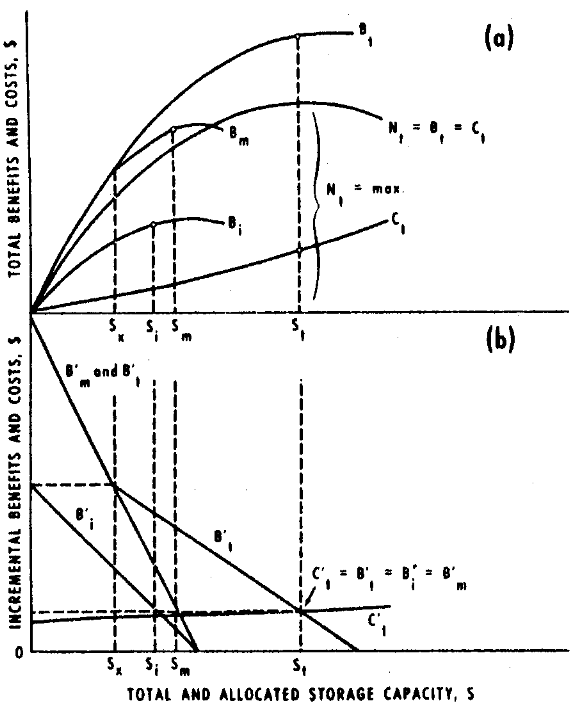


FIGURE 4. MAXIMIZING BENEFITS FROM WATER STORAGE

Aggregate net benefits N_t in Figure 4 would be maximized if S_t units of total storage were planned, with S_i units allocated to irrigation and S_m units to municipal-industrial purposes. At these optimal capacities, incremental costs of storage are shown (in the lower section) to be equal to incremental total benefits as well as to incremental benefits for each purpose. Optimal positions on total benefit and cost functions are indicated by the small circles in the upper section of the figure. These denote points at which slopes of tangents to the functions would be equal, according to the condition $C_t^{'} = B_t^{'} = B_i^{'} = B_m^{'}$.

CAPITAL RESTRICTIONS AND RATES OF RETURN

Nearly all of the preceding discussion has focused on evaluating and combining resource development projects with reference to relations between total capitalized costs, total capitalized benefits, net benefits, the B/C ratio as average benefit per unit cost, and the incremental or marginal benefit-cost rates as representing primary choice indicators. No particular emphasis was placed on returns to investment capital as such which, in a planning environment of capital scarcity, may be of overriding concern in evaluating project feasibility and establishing development priorities. Investment returns were not stressed because of a belief that project planning in the United States is still by-and-large characterized by a preoccupation with the magnitude of B/C ratios and because of the article's related objective of clarifying their legitimate use for economic evaluation.

Giving more stress to the optimum use of investment capital as such would revolve around optimization principles conceptually similar to those already presented. In idealized and simplified terms, for example, capitalized costs C are separable into capital investment I, and recurring operation and maintenance charges V. The latter can be deducted from recurring total benefits B to give $B^{'}$ as a measure of returns to capital investment. Then $B^{'}/I$ is a measure of the average return per unit of investment. The ratios $\Delta B^{'}/\Delta I$ or $dB^{'}/dI$, respectively, give arc or point measures of marginal rates of return. The variable $B^{'}$ as returns to capital is the item to maximize and so has a role similar to that of B - C or net benefits as previously discussed. Increased investment would be justified provided $dB^{'}/dI$ as the "demand" for project investment funds exceeded a specified schedule of marginal interest rates as the investment "supply" function. The optimum or maximum justified investment would be the investment at which $dB^{'}/dI$ equaled the marginal interest rate. In allocating investment funds among competing projects, principles similar to those given for Case E above would be followed. That is, marginal returns to capital would be equated for all projects undertaken and should not exceed this rate in any project not undertaken.

AN ISSUE FOR FURTHER STUDY

The stimulus for this article was an observation that resource development in the United States is of a lumpy or whole project-by-project character. A related hypothesis is that this situation is due less to a preference for politically achieving an optimum "pork-barrel distribution" of projects than to the lack of information that would allow a distribution of development resources based on the internal economics of each project proposal. The points covered briefly herein, and more extensively in the various additional references listed, would be useful in examining the validity of this hypothesis.

Attracting the research resources necessary to examine this kind of issue is not easy, but a dynamic reordering of our research and other priorities may be necessary, if we are to justify the continued use of resources to improve the planning process through developing refinements in economic evaluation. Validation of the hypothesis would imply that "process economic research" (research to improve techniques and standards for economic evaluation) should continue and possibly be increased. A nullified hypothesis would imply that such research should be curtailed. If the hypothesis is considered tenable and important but is not examined, the utilitarian values of "process" economic research will remain unknown. If the hypothesis is considered tenable but not important enough to test out, the utilitarian value of continued process research would be regarded as an unimportant unknown in resource development.

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