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AN INTRODUCTION TO COST BENEFIT ANALYSIS

Background

Cost-Benefit Analysis (CBA) estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile. These projects may be dams and highways or can be training programs and health care systems.

The idea of this economic accounting originated with Jules Dupuit, a French engineer whose 1848 article is still worth reading. The British economist, Alfred Marshall, formulated some of the formal concepts that are at the foundation of CBA. But the practical development of CBA came as a result of the impetus provided by the Federal Navigation Act of 1936. This act required that the U.S. Corps of Engineers carry out projects for the improvement of the waterway system when the total benefits of a project to whomsoever they accrue exceed the costs of that project. Thus, the Corps of Engineers had created systematic methods for measuring such benefits and costs. The engineers of the Corps did this without much, if any, assistance from the economics profession. It wasn't until about twenty years later in the 1950's that economists tried to provide a rigorous, consistent set of methods for measuring benefits and costs and deciding whether a project is worthwhile. Some technical issues of CBA have not been

wholly resolved even now but the fundamental presented in the following are well established.

Principles of Cost Benefit Analysis

One of the problems of CBA is that the computation of many components of benefits and costs is intuitively obvious but that there are others for which intuition fails to suggest methods of measurement. Therefore some basic principles are needed as a guide.

There Must Be a Common Unit of Measurement

In order to reach a conclusion as to the desirability of a project all aspects of the project, positive and negative, must be expressed in terms of a common unit; i.e., there must be a "bottom line." The most convenient common unit is money. This means that all benefits and costs of a project should be measured in terms of their equivalent money value. A program may provide benefits which are not directly expressed in terms of dollars but there is some amount of money the recipients of the benefits would consider just as good as the project's benefits. For example, a project may provide for the elderly in an area a free monthly visit to a doctor. The value of that benefit to an elderly recipient is the minimum amount of money that that recipient would take instead of the medical care. This could be less than the market value of the medical care provided. It is assumed that more esoteric benefits such as from preserving open space or historic sites have a finite equivalent money value to the public.

Not only do the benefits and costs of a project have to be expressed in terms of equivalent money value, but they have to be expressed in terms of dollars of a particular time. This is not just due to the differences in the value of dollars at different times because of inflation. A dollar available five years from now is not as good as a dollar available now. This is because a dollar available now can be invested and earn interest for five years and would be worth more than a dollar in five years. If the interest rate is r then a dollar invested for t years will grow to be $(1+r)^t$. Therefore the amount of

money that would have to be deposited now so that it would grow to be one dollar t years in the future is $(1+r)^{-t}$. This called the discounted value or present value of a dollar available t years in the future.

When the dollar value of benefits at some time in the future is multiplied by the discounted value of one dollar at that time in the future the result is discounted present value of that benefit of the project. The same thing applies to costs. The net benefit of the projects is just the sum of the present value of the benefits less the present value of the costs.

The choice of the appropriate interest rate to use for the discounting is a separate issue that will be treated later in this paper.

CBA Valuations Should Represent Consumers or Producers Valuations As Revealed by Their Actual Behavior

The valuation of benefits and costs should reflect preferences revealed by choices which have been made. For example, improvements in transportation frequently involve saving time. The question is how to measure the money value of that time saved. The value should not be merely what transportation planners think time should be worth or even what people say their time is worth. The value of time should be that which the public reveals their time is worth through choices involving tradeoffs between time and money. If people have a choice of parking close to their destination for a fee of 50 cents or parking farther away and spending 5 minutes more walking and they always choose to spend the money and save the time and effort then they have revealed that their time is more valuable to them than 10 cents per minute. If they were indifferent between the two choices they would have revealed that the value of their time to them was exactly 10 cents per minute.

The most challenging part of CBA is finding past choices which reveal the tradeoffs and equivalencies in preferences. For example, the

valuation of the benefit of cleaner air could be established by finding how much less people paid for housing in more polluted areas which otherwise was identical in characteristics and location to housing in less polluted areas. Generally the value of cleaner air to people as revealed by the hard market choices seems to be less than their rhetorical valuation of clean air.

Benefits Are Usually Measured by Market Choices

When consumers make purchases at market prices they reveal that the things they buy are at least as beneficial to them as the money they relinquish. Consumers will increase their consumption of any commodity up to the point where the benefit of an additional unit (marginal benefit) is equal to the marginal cost to them of that unit, the market price. Therefore for any consumer buying some of a commodity, the marginal benefit is equal to the market price. The marginal benefit will decline with the amount consumed just as the market price has to decline to get consumers to consume a greater quantity of the commodity. The relationship between the market price and the quantity consumed is called the demand schedule. Thus the demand schedule provides the information about marginal benefit that is needed to place a money value on an increase in consumption.

Gross Benefits of an Increase in Consumption is an Area Under the Demand Curve

The increase in benefits resulting from an increase in consumption is the sum of the marginal benefit times each incremental increase in consumption. As the incremental increases considered are taken as smaller and smaller the sum goes to the area under the marginal benefit curve. But the marginal benefit curve is the same as the demand curve so the increase in benefits is the area under the demand curve. As shown in Figure 1 the area is over the range from the lower limit of consumption before the increase to consumption after the increase.

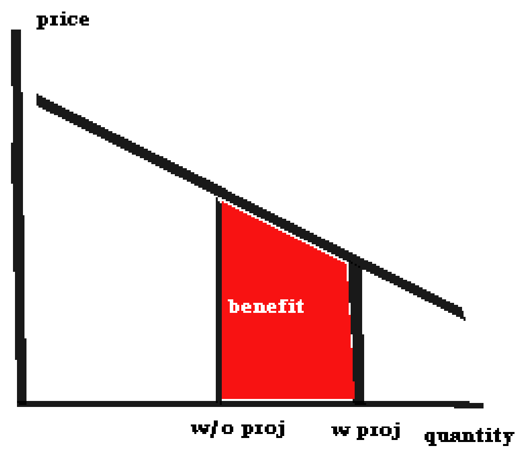

Figure 1

When the increase in consumption is small compared to the total consumption the gross benefit is adequately approximated, as is shown in a welfare analysis, by the market value of the increased consumption; i.e., market price times the increase in consumption.

Some Measurements of Benefits Require the Valuation of Human Life

It is sometimes necessary in CBA to evaluate the benefit of saving human lives. There is considerable antipathy in the general public to the idea of placing a dollar value on human life. Economists recognize that it is impossible to fund every project which promises to save a human life and that some rational basis is needed to select which projects are approved and which are turned down. The controversy is defused when it is recognized that the benefit of such projects is in reducing the risk of death. There are many cases in which people voluntarily accept increased risks in return for higher pay, such as in the oil fields or mining, or for time savings in higher speed in automobile travel. These choices can be used to estimate the personal cost people place on increased risk and thus the value to them of reduced risk. This computation is equivalent to placing an economic value on the expected number of lives saved.

The Analysis of a Project Should Involve a *With* Versus *Without* Comparison

The *impact* of a project is the difference between what the situation in the study area would be with and without the project. This that when a project is being evaluated the analysis must estimate not only what the situation would be with the project but also what it would be without the project. For example, in determining the impact of a fixed guideway rapid transit system such as the Bay Area Rapid Transit (BART) in the San Francisco Bay Area the number of rides that would have been taken on an expansion of the bus system should be deducted from the rides provided by BART and likewise the additional costs of such an expanded bus system would be deducted from the costs of BART. In other words, the alternative to the project must be explicitly specified and considered in the evaluation of the project. Note that the with-and-without comparison is not the same as a before-and-after comparison.

Another example shows the importance of considering the impacts of a project and a with-and-without comparison. Suppose an irrigation project proposes to increase cotton production in Arizona. If the United States Department of Agriculture limits the cotton production in the U.S. by a system of quotas then expanded cotton production in Arizona might be offset by a reduction in the cotton production quota for Mississippi. Thus the impact of the project on cotton production in the U.S. might be zero rather than being the amount of cotton produced by the project.

Cost Benefit Analysis Involves a Particular Study Area

The impacts of a project are defined for a particular study area, be it a city, region, state, nation or the world. In the above example concerning cotton the impact of the project might be zero for the nation but still be a positive amount for Arizona.

The nature of the study area is usually specified by the organization sponsoring the analysis. Many effects of a project may "net out" over

one study area but not over a smaller one. The specification of the study area may be arbitrary but it may significantly affect the conclusions of the analysis.

Double Counting of Benefits or Costs Must be Avoided

Sometimes an impact of a project can be measured in two or more ways. For example, when an improved highway reduces travel time and the risk of injury the value of property in areas served by the highway will be enhanced. The increase in property values due to the project is a very good way, at least in principle, to measure the benefits of a project. But if the increased property values are included then it is unnecessary to include the value of the time and lives saved by the improvement in the highway. The property value went up because of the benefits of the time saving and the reduced risks. To include both the increase in property values and the time saving and risk reduction would involve double counting.

Decision Criteria for Projects

If the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile. This is equivalent to the condition that the net benefit must be positive. Another equivalent condition is that the ratio of the present value of the benefits to the present value of the costs must be greater than one.

If there are more than one mutually exclusive project that have positive net present value then there has to be further analysis. From the set of mutually exclusive projects the one that should be selected is the one with the highest net present value.

If the funds required for carrying out all of the projects with positive net present value are less than the funds available this means the discount rate used in computing the present values is too low and does not reflect the true cost of capital. The present values must be recomputed using a higher discount rate. It may take some trial and error to find a discount rate such that the funds required for the

projects with a positive net present value is no more than the funds available. Sometimes as an alternative to this procedure people try to select the best projects on the basis of some measure of goodness such as the internal rate of return or the benefit/cost ratio. This is not valid for several reasons.

The magnitude of the ratio of benefits to costs is to a degree arbitrary because some costs such as operating costs may be deducted from benefits and thus not be included in the cost figure. This is called *netting out* of operating costs. This netting out may be done for some projects and not for others. This manipulation of the benefits and costs will not affect the net benefits but it may change the benefit/cost ratio. However it will not raise the benefit cost ratio which is less than one to above one. For more on this topic see Benefit/ cost Ratio Magnitude.

An Example

To illustrate how CBA might be applied to a project, let us consider a highway improvement such as the extension of Highway 101 into San Jose. The local four-lane highway which carried the freeway and commuter traffic into San Jose did not have a median divider and its inordinate number of fatal head-on collisions led to the name "Blood Alley." The improvement of the highway would lead to more capacity which produces time saving and lowers the risk. But inevitably there will be more traffic than was carried by the old highway.

The following is a highly abbreviated analysis using hypothetical data.

TRIP DATA	No Extension, "Blood Alley" Only	101 Extension and "Blood Alley"
Rush Hours		
Passenger Trips (per hour)	3,000	4,000

Trip Time (minutes)	50	30
Value of Time ($/minute)	$0.10	$0.10
Nonrush Hours		
Passenger Trips (per hour)	500	555.55
Trip Time (minutes)	35	25
Value of Time ($/minute)	$0.08	$0.08
Traffic Fatalities (per year)	12	6

The data indicates that for rush-hour trips the time cost of a trip is $5 without the project and $3 with it. It is assumed that the operating cost for a vehicle is unaffected by the project and is $4.

The project lowers the cost of a trip and the public responds by increasing the number of trips taken. There is an increase in consumer surplus both for the trips which would have been taken without the project and for the trips which are stimulated by the project.

For trips which would have been taken anyway the benefit of the project equals the value of the time saved times the number of trips. For the rush-hour trip the project saves $2 and for the nonrush-hour trip it saves $0.80. For the trips generated by the project the benefit is equal to one half of the value of the time saved times the increase in the number of trips.

The benefits per hour are:

TYPE	Trips Which Would Be Taken Anyway	Trips Generated By the Project	Total
Rush Hour	6,000.00	1,000.00	7,000.00
Nonrush Hour	400.00	22.22	422.22

To convert the benefits to an annual basis one multiplies the hourly benefits of each type of trip times the number of hours per year for that type of trip. There are 260 week days per year and at six rush hours per weekday there are 1560 rush hours per year. This leaves 7200 nonrush hours per year. With these figures the annual benefits are:

TYPE	Trips Which Would Be Taken Anyway	Trips Generated By the Project	Total
Rush Hour	$9,360,000	$1,560,000	$10,020,000
Nonrush Hour	$2,880,000	$160,000	$3,040,000
Total	$12,240,000	$1,720,000	$13,960,000

The value of the reduced fatalities may be computed in terms of the equivalent economic value people place upon their lives when making choices concerning risk and money. If the labor market has wages for occupations of different risks such that people accept an increase in the risk of death of 1/1,000 per year in return for an increase in income of $400 per year then a project that reduces the risk of death in a year by 1/1000 gives a benefit to each person affected by it of $400 per year. The implicit valuation of a life in this case is $400,000. Thus benefit of the reduced risk project is the expected number of lives saved times the implicit value of a life. For the highway project this is 6x$400,000= $2,400,000 annually.

The annual benefits of the project are thus:

TYPE OF BENEFIT	VALUE OF BENEFITS PER YEAR
Time Saving	$13,960,000
Reduced Risk	$2,400,000

Let us assume that this level of benefits continues at a constant rate over a thirty-year lifetime of the project.

The cost of the highway consists of the costs for its right-of-way, its construction and its maintenance. The cost of the right-of-way is the cost of the land and any structures upon it which must be purchased before the construction of the highway can begin. For purposes of this example the cost of right-of-way is taken to be $100 million and it must be paid before any construction can begin. At least part of the right-of- way cost for a highway can be recovered at the end of the lifetime of the highway if it is not rebuilt. For the example it is assumed that all of the right-of-way cost is recoverable at the end of the thirty-year lifetime of the project. The construction cost is $200 million spread evenly over a four-year period. Maintenance cost is $1 million per year once the highway is completed.

The schedule of benefits and costs for the project are as follows:

TIME (year)	BENEFITS ($millions)	RIGHT-OF-WAY ($millions)	CONSTRUCTION COSTS ($millions)	MAINTENANCE ($millions)
0	0	100	0	0
1-4	0	0	50	0
5-29	16.36	0	0	1

30	16.36	-100	0	1

The benefits and costs are in constant value dollars; i.e., there was no price increase included in the analysis. Therefore the discount rate used must be the real interest rate. If the interest rate on long term bonds is 8 percent and the rate of inflation is 6 percent then the real rate of interest is 2 percent. Present value of the streams of benefits and costs discounted at a 2 percent back to time zero are as follows:

	PRESENT VALUE ($ millions)
Benefits	304.11
Costs	
Right-of-Way	44.79
Construction	190.39
Maintenance	18.59
Total Costs	253.77
Net Benefits	50.35

*independent rounding

The positive net present value of $50.35 million and benefit/cost ratio of 1.2 indicate that the project is worthwhile if the cost of capital is 2 percent. When a discount rate of 3 percent is the benefit/cost ratio is slightly under 1.0. This means that the internal rate of return is just under 3 percent. When the cost of capital is 3 percent the project is not worthwhile.

It should be noted that the market value of the right-of-way understates the opportunity cost of having the land devoted to the highway. The land has a value of $100 million because of its income after property taxes. The economy is paying more for its alternate use but some of the payment is diverted for taxes. The discounted presented value of the payments for the alternate use might be more like $150 million instead of $100 million. Another way of making this point is that one of the costs of the highway is that the local governments lose the property tax on the land used.

Summary

By reducing the positive and negative impacts of a project to their equivalent money value Cost-Benefit Analysis determines whether on balance the project is worthwhile. The equivalent money value are based upon information derived from consumer and producer market choices; i.e., the demand and supply schedules for the goods and services affected by the project. Care must be taken to properly allow for such things as inflation. When all this has been considered a worthwhile project is one for which the discounted value of the benefits exceeds the discounted value of the costs; i.e., the net benefits are positive. This is equivalent to the benefit/cost ratio being greater than one and the internal rate of return being greater than the cost of capital.

History of Cost-Benefit Analysis

CBA has its origins in the water development projects of the U.S. Army Corps of Engineers. The Corps of Engineers had its origins in the French engineers hired by George Washington in the American Revolution. For years the only school of engineering in the United States was the Military Academy at West Point, New York.

In 1879, Congress created the Mississippi River Commission to "prevent destructive floods." The Commission included civilians but the president had to be an Army engineer and the Corps of Engineers always had veto power over any decision by the Commission.

In 1936 Congress passed the Flood Control Act which contained the wording, "the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs." The phrase if the benefits to whomsoever they may accrue are in excess of the estimated costs established cost-benefit analysis. Initially the Corps of Engineers developed ad hoc methods for estimating benefits and costs. It wasn't until the 1950s that academic economists discovered that the Corps had developed a system for the economic analysis of public investments. Economists have influenced and improved the Corps' methods since then and cost-benefit analysis has been adapted to most areas of public decision-making.

Additional Topics

- The Relationship Between Private Profitability and Net Social Benefit
- Resolving the Discrepancies Between the Surpluses Approach to CBA and the Net Social Benefit Approach
- The Net Social Benefit of Improved Forecasts

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