Literature Review

Cost-Benefit Analysis of Material Recycle Stream Options at the Site of the Former Portsmouth Gaseous Diffusion Plant (PORTS) at Piketon, Ohio

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Introduction

The purpose of this report is to provide an independent review of cost and benefit estimates for material recycle stream options performed by Fluor-B&W Portsmouth LLC, the U.S. Department of Energy's (DOE) contractor at the former Portsmouth Gaseous Diffusion Plant (PORTS) in Piketon, Ohio. Specifically, this analysis reviews cost estimates for the two projects. One is the X-100 Complex consisting of four separate facilities: X-100, X-100B, X-101, and X-109C. The second project is the recycling of an old locomotive train engine. For purpose of this study, the main research question addressed in this report is: Which of the two proposed options – waste disposal or recycling – is more cost-effective? Answering this question requires measurement and comparison not only of the costs associated with each option but also the value of recovered assets. Therefore we employ a cost/benefit framework in the analysis of each project.

Briefly stated, the purpose of Cost/Benefit analyses is to act as an aid in decision making. The basic idea behind such an analysis is to catalogue the impacts of a proposed project systematically as benefits, costs, or transfers from one party to another, to value them in dollars, and to compare them to observe if the benefits of the proposed venture outweigh its costs.

Given the simplicity of this definition, it would seem that preparing a benefit cost analysis would be a fairly straightforward thing to do, and, indeed, much of what is done is fairly clear and unambiguous. There are several areas, however, where judgments must be made and caution is in order. First of all, a Cost/Benefit analysis can be private in scope and deal only with the costs of a particular firm in making an investment. Often, however, there are a number of stakeholders involved and the analysis will have to assess the effects of a project on a broader spectrum of winners and losers in the area or region involved. Second, and equally important, a Cost/Benefit analysis must account for cases where the private market fails to capture the true social costs or benefits of a given input or output and adjustments have to be made to deal with this in an accurate manner. For example, where a public cost would differ from a private cost would be the construction of a road through a pristine woodland. In addition to the private cost of the road, the public cost would include the loss of the scenic beauty and consumers' willingness to pay for that beauty. Another example where a public benefit would differ from a private benefit would be a vaccination program. In addition to the immunity to disease given to the people actually vaccinated, other people (who were not vaccinated) would risk less exposure to the disease and would thus face lower infection rates.

Basic Steps of Benefit/Cost Analysis

As pointed out by Boardman et al. (2011), in constructing a Cost/Benefit analysis it is both helpful and informative to break it down into a number of component steps, and examine each one of these steps individually. First, the analyst needs to specify the set of alternative projects. This is especially helpful if there are a number of ways to proceed to a given outcome (e.g. an employment target). Other times, however, there may be only one project to analyze (e.g. whether to do a project or not) and in this case the project is compared with the status quo.

Second, and very importantly, one must look at whose benefits and costs matter[1]. In the literature, this is often referred to as *standing*. If, for example, a cost/benefit analysis is looking only at the viability of a firm's private investment, the costs and benefits to the firm are all that matters. If, however, there are a number of stakeholders located in various counties or states, the impact on them must be considered as well.

Third, the literature suggests that the Cost/Benefit analyst should identify impact categories, catalogue them, and set measurement indicators. The term "impact categories" refers to the costs and benefits themselves. Costs are generally thought of as the inputs to a project (e.g. the gravel to be used in the construction of a road) and benefits are generally thought of here as the outputs[2] of a project (e.g. the traffic of the vehicles that use that road). While cataloguing this list may be tedious and time consuming, it is important that it be as complete and well thought out as possible so that the analyst can avoid mistakes that may ultimately lead to incorrect conclusions.

Fourth, the analyst must attempt to predict the impacts quantitatively over the life of a project. Most projects are designed to last more than a single year. Furthermore, the benefits of a project may not be accruing until several years into the project. Nevertheless the analyst should attempt to make the best predictions as to what those benefits may be (e.g. the price of an output several years from now) in order to see if the future benefits are worth the present costs.

Fifth, all of the costs and benefits of a project need to be monetized. In a very real sense this is the most crucial step in the whole analysis since the ultimate goal of the analysis is to compare the dollar value of the benefits and cost of the project. Nonetheless, this may be very difficult for a number of reasons. Prices and costs may occur at future dates and may not be known with certainty. Furthermore, certain costs (i.e. the cost of someone being injured on the job) may be hard to quantify. It may thus be helpful to look at past analyses of similar projects or to borrow estimates from other researchers on these costs (e.g. the expected cost of job related injuries) to include in the analysis[3]. Indeed, even, if no explicit data on these things can be obtained they need to be mentioned in the analysis to aid in making the final go/no go decision.

Further Considerations

Before a recommendation can be made by the Cost/Benefit analyst two other important considerations must be made. Inputs and outputs must be discounted over time and sensitivity analysis must be performed. As we have already noted, both benefits and costs occur over time and benefits and costs that occur in different years must be summed together if we are to have a single cost and a single benefit number. To do this we discount benefits and costs by the use

[1] See for example Boardman, Vining, and Watters (1993).

[2] It should also be noted that the analyst must show that there is a cause and effect relationship between the project and the outputs. Not doing this can lead to erroneous conclusions. See Williamson (1992).

[3] There are numerous statistical studies looking at topics including the value of job related injuries, the value of time spent, the cost of crime, and the value of human life etc. The best surveys of these topics include articles by Miller (2000), Mrozek and Taylor (2002), Viscusi and Aldy (2003), and Miller (1989).

of a discount (i.e. interest) rate. If for example a dollar is to be received as a benefit a year from now and the rate of discount is 10%, then the present value of that dollar must be calculated using the formula

$$PV = \frac{FV}{(1 + r)}$$

where PV stands for present value, FV stands for future value, and r is the rate of discount. In the case of the dollar, PV = \$1/(1 + 0.1) = \$ 0.91 indicating that one dollar received a year from now is equivalent to 91 cents received today. By summing the PV one year out with similarly discounted values for benefits that occur today, two years from now, three years from now etc., then, a cumulative estimate can be obtained for the present value of all benefits in all time periods. A similar estimate can be derived for costs. This allows for a benefit/cost comparison to see if the monetized sum of the benefits is greater or less than that of the costs.

As the foregoing discussion makes plain, there may be considerable uncertainty about both the predicted impact and the appropriate monetary valuation of each unit of the impact. For example, the analyst may be uncertain about the future price of some output or the proper rate of interest to use as a discount rate. Furthermore, the analyst may be unsure of exactly whose benefits and costs should count or what the appropriate value of job related injuries is. To try to deal with these uncertainties it is best that the Cost/Benefit analyst make use of Sensitivity Analysis. Rather than relying on a single set of numbers and parametric values, the analyst should vary these quantities to see the result that this has on the economic viability of the project. It may be the case, for example, that a project has a positive net present value if a 5% rate of discount is used but a negative net present value if a 10% rate of discount is used. This, in turn, may cast doubt about proceeding with the project. If, on the other hand, the project is seen to have positive net present value under a wide range of discount rates this would suggest that the policymakers should proceed with it, even in the face of some uncertainty. In practice, one has to use judgment and focus on the most important assumptions rather than mindlessly varying every parameter. Nevertheless, a good analyst can usually distill the most important parameters to vary and concentrate on them. Here, too, good statistical analysis can be a helpful aid and methods such as Monte Carlo Analysis have proven to be a valuable tool in a number of cases[4]. By then using sound statistical methods, the analyst can turn Cost/Benefit analysis into an informative and reliable tool for policy making.

Cost-Effectiveness Analysis

While, as stated above, monetizing the benefits and costs of a project are an integral component of a Cost/Benefit analysis, it may sometimes be the case that the analyst is either unable or unwilling to monetize the major benefit[5]. In this case it may be best to turn to an

[4] For a good example of the use of Monte Carlo Analysis within a cost benefit setting see Nichols (2001).

[5] For example when there is some controversial subject involved such as evaluating the value of a human life, evaluating the value of an endangered species, or evaluating the value of an old growth forest.

alternative to Cost/Benefit analysis called Cost-Effectiveness analysis[6]. Under this type of analysis the analyst looks at some non-monetized benefit (e.g. some level of recycling to be done in an area or state) and sees which of several alternatives can achieve this in the least cost fashion. This involves the construction of ratios giving the amount of the benefit achieved under each alternative to its respective cost, and then comparing the ratios to see which one of them is highest.[7]

This kind of analysis does have the advantage of avoiding the philosophical problems that Cost/Benefit analysis encounters in monetizing benefits. The main drawback of such an approach, however, is that it does not "directly allow the analysts to conclude that the highest-ranked policy contributes to greater efficiency"[8]. Nevertheless it does seem to be gaining wider acceptance and serves to be a viable substitute when a full-fledged Cost/Benefit analysis is deemed inappropriate or turns out to be too complicated to complete.

Sensitivity Analysis

Most decisions involve risk and uncertainty and these should be incorporated, to the extent possible, in the decision-making process. Uncertainty permeates cost-benefit analysis, since the estimation of costs and benefits relies on data and scenarios that are sensitive to a changing economic environment. Domestic and international monetary and fiscal policies, changing market conditions and exogenous shocks, such as weather variability, are examples of variables that may affect interest rates, prices and access to credit, and ultimately have an impact on the actual costs and benefits of specific projects. Anticipating the possibility and nature of the variability of key components of a cost-benefit study can provide the decision-maker with a sense of how sensitive his choices are to a changing economic environment. This, in turn, may help the decision maker to avoid costly decisions and prepare for different scenarios that may emerge in the future. For these reasons, sensitivity analysis is considered an essential part of cost benefit analysis.[9]

Several strategies have been proposed to tackle uncertainty and perform sensitivity analysis in economic studies in general and cost-benefit analysis in particular. Perhaps the most common approach is to identify key economic variables (such as prices, interest rates, rate of economic growth, etc.) for the project under consideration and specify reasonable scenarios for each of these variables. Specification of scenarios often relies on expert judgment. Once the scenarios for the relevant variables are specified, the cost-benefit study is repeated for each scenario and the resulting benefit-cost ratios or spreads are computed and contrasted.

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[6] For an informative review of the techniques involved in Cost-Effectiveness analysis see Boardman et al. (2011) and Garber (2000).

[7] There can be a great amount of uncertainty involved in the construction of these ratios. For this reason Monte Carlo simulations are particularly attractive here, and, as a consequence are often used in Cost-Effectiveness analysis. For the use of Monte Carlo simulations in Cost-Effectiveness analysis see Fenwick, Claxton, and Sculpher (2001).

[8] Boardman et al. (2011), p. 43.

[9] See Boardman et al. (2011), for example.

The main shortcoming from the scenario analysis described above is its high degree of subjectivity. When subjective scenario analysis cannot be conducted or is not a desirable option, a number of alternative strategies can be implemented. Among the most popular approaches are parametric and non-parametric confidence interval estimation, Monte Carlo analysis, bootstrapping and the jackknife estimation technique.[10] All of these acknowledge the random nature of the data and try to estimate a range of likely outcomes for the parameters of interest.

Consider first a parametric approach to sensitivity analysis. Suppose the variable of concern is the price of an input, which is assumed to be randomly distributed with a normal (Gaussian) density function with a known variance. If a single value for the price of the input is observed and is assumed to be a reasonable approximation for the mean price, then a confidence interval for this price can be constructed based on the known variance. In practice, a more likely scenario is for a sample of prices to be observed and for the true variance to be unknown. In this case, the desired confidence interval for mean price can be constructed around the sample mean using the estimated sample variance and a student's t distribution. Finally, in some applications, there is no compelling reason to assume that a variable of concern follows any particular distribution (like the normal distribution). In these cases, an empirical distribution emerging from the observed data might be the best starting point for the sensitivity analysis. The empirical distribution assigns frequency to ranges of the data. The most commonly used representation of empirical distributions is the histogram. Other representations of this kind exist and, like histograms, do not depend on parameters of a hypothesized distribution (such as the normal distribution is fully described by the parameters mean and variance of the random variable). For this reason, they are called non-parametric distribution functions.

The use of sample observations to conduct sensitivity analysis is further explored with Monte Carlo or stochastic simulations. In a Monte Carlo simulation, a parameter of concern is estimated based on a sample of size n (examples of parameters are the sample mean or coefficients in a regression model) and the distribution of the variable underlying the estimation of the parameter is assumed to be known. The idea then is to create an artificial sample of size n^* by randomly drawing n^* observations from the assumed distribution and estimating the parameter of concern again (such as the sample mean). We repeat this exercise many times, say 1,000 times, and estimate the parameter of concern each time. We end up with 1,000 estimates of the parameter, plus the original estimate from the actual sample and can then estimate the histogram or distribution of the parameter. This will provide a "reasonable" range of results in our cost-benefit study.

The idea of creating a distribution of the parameters of concern based on the original sample is further explored in the bootstrapping and jackknifes methods. Bootstrapping is a particular type of Monte Carlo study. The fundamental difference is that in a bootstrapping simulation exercise, no assumption is made about the distribution of the original data. As in the Monte Carlo studies described in the previous paragraph, a number of samples are artificially created and the parameter of concern is estimated in each case, along with the distribution of

[10] For a discussion involving parametric, Monte Carlo and bootstrap methods applied to cost effectiveness analysis, see Nixon et al. (2010).

these parameters. Different from the traditional Monte Carlo studies, the artificial samples are created by randomly drawing observations from the original sample with replacement. Bootstrapping might be a particularly attractive approach to estimate the variance of benefit-cost parameters in complex cost-benefit studies. This is true, because even if the distribution functions of the key variables entering the study are known, the final benefit-cost ratio might be a complex function of these key variables and it might not be possible to calculate its distribution function other than numerically.[11]

Finally, the jackknife resampling technique uses a sample of data to calculate the parameter of concern. Then, a new sample of data is created by leaving out one observation (or a set of observations), and the corresponding parameter of concern is estimated for this smaller sample. In a sample of size *n* and removing one observation at a time, *n'* new subsamples are created and *n'* new parameters are estimated. The *n'* estimates obtained by the jackknife procedure plus the original parameter estimate from the complete sample are then used to calculate the bias and variance of the original parameter.

Estimation of confidence intervals for parameter estimates is a fundamental and prevalent issue in a number of different contexts in economics. Several aspects of the techniques discussed here are further discussed in more detail at various levels of sophistication in the economics and econometric literature. A small sample of classical references in the econometrics literature includes Davidson and McKinnon (1993), Greene (2011), Kennedy (2008) and Pindyck and Rubinfeld (1997).

Methodology

The study is based on volumetric and cost data provided by the PORTS site contractor. The data include estimates for the capital and labor for recycle and disposal options as well as potential recovery value of assets. It is important to understand that estimates provided by the contractor are treated as discrete, fixed values. This typically is not the case in the real world as many input variables are not fixed and are therefore subject to variability and uncertainty. Rather than using “ballpark figures”, it is possible to produce better estimates by controlling how these values are calculated. The Monte Carlo method is a way of estimating project cost based on the generation of multiple trials to compute expected value of a particular variable. Our key steps are as follows:

- Determine variables and categories that will most likely be subject to uncertainty.
- For each variable generate a sample of random values drawn from a particular probability distribution.
- Compute expected value as a mean of the simulated values.
- Aggregate costs and recovery values to determine effectiveness of each option.

Using the Monte Carlo approach essentially exposes areas of uncertainty, which are typically hidden in the traditional methods of estimating costs. This is very important for public projects as it allows decision-makers to examine probability outcomes for each variable.

[11] See Briggs et al. (1997) for example.

References

Boardman, Anthony, Greenberg, David, Vining, Aidan, and David Weimer (2011). "Cost-Benefit Analysis: Concepts and Practice", 4th Edition, 541 pages, Prentice Hall publishers, New York.

Briggs, A.H., D.E Wonderling and C.Z. Mooney (1997). "Pulling cost-effectiveness analysis up by its bootstraps: a non-parametric approach to confidence interval estimation". *Health Economics*, 6 (4), pp. 327-40.

Davidson, R. and J.G. McKinnon (1993). "Estimation and inference in econometrics". Oxford University Press.

Greene, W. (2011). "Econometric analysis", 7th edition, Prentice Hall.

Kennedy, P. (2008) "A guide to econometrics", 6th edition, Wiley-Blackwell.

Nixon, R.M., D. Wonderling and R.D. Grieve (2010). "Non-parametric methods for cost-effectiveness analysis: The central limit theorem and bootstrap compared". *Health Economics*, 19 (3), pp. 316-33.

Pindyck, R.S. and D.L. Rubinfeld (1997). "Econometric models and economic forecasts", 4th edition, McGraw-Hill/Irwin.

Boardman, Anthony, Vining, Aidan, and W.G. Waters II, "Costs and Benefits through Bureaucratic Lenses: Example of a Highway Project, " *Journal of Policy Analysis and Management* 12(3) 1993, 532-555.

Boardman, Anthony, Greenberg, David, Vining, Aidan, and David Weimer, Cost-Benefit Analysis: Concepts and Practice 4th Edition, 541 pages, 2011, Prentice Hall publishers, New York.

Fenwick, Elisabeth, Claxton, Karl and Mark Sculpher, "Representing Uncertainty: The Role of Cost-Effectiveness Acceptability Curves," *Health Economics* 10(8) 2001, 779 – 787.

Garber, Alan M., "Advances in Cost-Effectiveness Analysis," In Anthony J. Culyer and Joseph P. Newhouse, eds. , Handbook of Health Economics, pp. 181-221, Elsevier Publishers, New York.

Miller, Ted R., *Narrowing the Plausible Range around the Value of Life* (Washington D.C.: The Urban Institute, 1989)

Miller, Ted R., "Variations Between Countries in Values of Statistical Life*," Journal of Transport Economic and Policy* 34(2) 2000, 169-188.

Mrozek, Janusz R. and Laura O. Taylor, "What Determines the Value of Life? A Meta-Analysis," Journal of Policy Analysis and Management 21(2) 2002, 253-270.

Nichols, Kristin, “Cost Benefit Analysis of a Strategy to Vaccinate Healthy Working Adults Against Influenza” *Archives of Internal Medicine* 161(5) 2001, 749-759.

Viscusi, W. Kip and Joseph Aldy, “ the Value of Statistical Life: A Critical Review of Market Estimates Throughout the World”, Journal of Risk and Uncertainty 27(1) 2003, 5 -76.

Williamson, Robert, “Pulp Cleanup may Be Waste of Money,” Toronto Globe and Mail, December 23, 1992. Pp. A1, A6.