THE DISCOUNT RATE IN LIFE CYCLE COST ANALYSIS OF TRANSPORTATION PROJECTS

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ABSTRACT
Although there is a widespread agreement on the need to discount future costs in monetary-based evaluation techniques of long-term transportation projects, there is less agreement on the specific discount rate that should be employed in the analysis. The choice of the discount rate is ultimately a policy decision; but even when the philosophical approach is set by the policy makers and a general guidance is issued, there still remain many questions to be addressed—questions such as: What are the tangible rates that decode the preferred rationale set by the policy makers? What are the data sources to obtain these rates? How can we deal with the economic aspect of uncertainty in the actual analysis? The research presented in this paper does not aim at adding another philosophical approach for the discount rate into the on-going debate; rather it aims at providing a practical insight for the practitioner analyst as regards the effect of implementing on-hand approaches and guidance on the discount rate. The research infers several probable scenarios for choosing and applying the discount rate from past academic research, federal guidance, or state-of-the-practice at transportation agencies. By developing a study methodology based on a look-back life cycle cost analysis that employs timely data, these scenarios are tested and analyzed in depth. The results of these analyses endorsed some guidance's while, on the other hand, uncovered the shortcomings of other proposed approaches. At the end, the paper concludes with recommending good-practice guidance for choosing the discount rate.

INTRODUCTION

When monetary-based evaluation techniques are used for analyzing long-term public investments, *discounting* is an essential element of the overall analysis. The theory goes as follows: as time has money value, a dollar after one year is worth less than the present dollar. Accordingly, discounting refers to the process of converting the costs and benefits encountered at different points in time into a single time dimension by employing a discount rate that denotes the change in the money value per time period (generally one year).

The discount rate used for the evaluation of public projects differs from the interest rate employed in private investments; as such, it is sometimes referred to as the social discount rate to differentiate between both rates. The discount rate is a highly significant factor in economic evaluation exercises and can have a major influence on the outcome.

Although there is a widespread agreement on the need to discount future costs, there is less agreement on the specific discount rate that should be employed in the analysis. The choice of the social discount rate is a problem that has perplexed the economics profession for at least the past 30 years. Many economists attempted to derive the correct discount rate for public-sector projects. Despite the efforts of these researchers, no consensus was reached. A big attempt was made during the early 1980s at a conference by the “Resources for the Future” organization. During this conference two of the most prominent economists, Kenneth Arrow (1972 Nobel Prize winner) and Joseph Stiglitz, again struggled with this problem and they failed to reach a consensus (1, 2). This ongoing debate has brought about a number of conceptual approaches for determining the social discount rate.

The theoretical economics literature considers two main approaches (and the weighted average thereof) for the estimation of the public-sector discount rate. The first approach is based on the estimation of the opportunity cost of capital and requires assumptions about the alternative uses of resources used for investment in a project. The second approach is based on the idea of social time preference and considers the economic logic underlying the preference for present—as opposed to future—consumption.

In turn, the estimation of the discount rate based on any of these approaches can be accomplished using various techniques. For instance, the opportunity cost of capital can be estimated using: a) Evaluation Studies, b) Macroeconomic Data, c) The Real Cost of Borrowing, and d) Trial and Error (3).

The brief introduction about the discount rate is necessary to demonstrate the deliberations that are taking place with no end in sight. The choice of the discount rate is eventually a “policy decision”. Many countries and agencies specify the discount rate to be employed in public projects that represent their outlook or as a means to achieve their intentional policies and goals.

Perhaps the numerous philosophical debates about the choice of discount rate had weighed down on any studies that aimed at providing the practicing analysts with factual recommendations on what discount rate they should use. To be more precise, even when the philosophical approach is set by the policy makers and a general guidance is issued, there still remain many questions to be addressed—questions such as: What are the tangible rates that represent the preferred rationale set by the policy makers properly? What are the data sources to obtain these rates? How can we deal with the economic aspect of uncertainty in the actual analysis?

It is not the intention of this paper to introduce one more philosophical rationale or position on the selection of the appropriate discount rate along these lines; neither will it advocate any one of the approaches mentioned above. Rather, its main objective is to present an in-depth discussion of the basic formulation of the discount rate, the actual state-of-the-practice and governmental guidance for choosing it, and the practical statistical approaches for applying the selected discount rate. This in-depth discussion results from investigating the inferences of employing different "scenarios" for the discount rate—in a quest for presenting a comprehensible guidance on this process. After this introductory section, the next section presents the discount rate formulations, followed by a revision of the approaches followed in choosing the discount rate for evaluating public transportation projects out of which eleven scenarios are inferred. Then the research methodology is presented along with its implementation and a detailed analysis of the results. The paper ends, after that, with a conclusion that provides good-practice guidance for choosing the discount rate.

Although this study tackles this issue specifically in the transportation sector, the modus operandi of implementation and the final conclusions could also be made applicable to other public sectors when time and discounting are essential elements in their evaluation.

MODELING THE DISCOUNT RATE

As discussed in the introduction of this paper, the discount rate and the interest rate are two terms that are sometimes used interchangeably to describe a value in percent used for converting future costs and benefits encountered over the lifetime of a project into a single time dimension. Abstractly, the economic theory identifies two factors that affect the discount rate—"the earning capacity of money" and "the inflation". Some economic literature also includes "the risk" as a third factor that can be accounted for in estimating the discount rate.

The following two equations are employed to convert future cost into present cost and vice versa (4).

$$F = P(1+r)^n \qquad \text{(Eq. 1)}$$

$$P = F\left[\frac{1}{(1+r)^n}\right] \qquad \text{(Eq. 2)}$$

where

P = The present-day cost or value; the present sum of money.

F = The cost sum at a future date, n periods from the present; the sum is equivalent to *P* with compound interest at *r* (discount rate) over n periods

r = Value in decimals representing a specific change over time periods; discount rate per period of time; it could be in this sense nominal or real depending on the nature of analysis.

n = Number of discount periods; it is mostly expressed in years

Further, the real discount rate can be estimated using the derived formula.

$$r^* = \frac{i - f}{1 + f} \qquad \text{(Eq. 3)}$$

Where

f = Inflation rate

i = Nominal interest rate

r^* = Real discount rate—an interest rate that has been adjusted to remove the effect of expected or actual inflation.

For the exact derivation of these formulas, the reader is referred to the reference (5).

CHOOSING THE DISCOUNT RATE

Before the computation can be made in the ex ante evaluation of long-term public project, a discount rate must be specified. This is true for all forms of cost-benefit analysis (B/C). Life Cycle Cost Analysis (LCCA) is no different than these other analyses. But the fact that the LCCA as applied in the transportation agencies where only the agency costs are considered (6)—could be regarded as a form of cost-effectiveness analysis—makes it possible to perform an evaluation study in the form of a "look-back" analysis that explicitly examines the real implications of choosing one discount rate against others in the LCCA. This section goes over the origins of the different scenarios of the discount rate that are scrutinized.

The results of a LCCA survey carried out by the authors of this paper (6) and the literature review about the patent choice of the discount rate in the LCCA for the evaluation of transportation infrastructure pointed out four main trends:

- The guidance provided by the Office of Management and Budget (OMB) in the White House Circular No. A-94 titled: "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" (7)
- The guidance provided by the Federal Highway Administration (FHWA), in their Interim Technical Bulletin No. FHWA-SA-98-079 titled" Life Cycle Cost Analysis in Pavement Design: In Search of Better Investment Decisions" (8)
- Type of synthetic discount rate similar to the one proposed by Philip Cady in 1985, when he derived a formula for estimating the discount rate to be used in the LCCA of highway investment specifically (9)
- The state-of-the-practice on the choice of the discount rate within SHAs as determined by the survey (6).

OMB Position

OMB circular A-94 (revision of October 1992) recommends discounting by 7% for cost-benefit analysis and by the treasury rate on bonds of maturity equal to the period of analysis for cost effectiveness analysis. Appendix C of this circular specifies the nominal and real treasury interest rate for 3-year, 5-year, 7-year, 10-year, 30-year maturities. This appendix is updated annually. Shorter maturity periods generally correspond to lower discount rates. The 2003 real treasury rates were 1.6, 1.9, 2.2, 2.5, and 3.2 for the above maturity periods respectively.

FHWA Position

The FHWA-SA-98-079 report published in September 1998 specifies that the discount rate needs to be consistent with the opportunity cost for the public at large. This opportunity cost for the public can be estimated from the US Government Treasury Bill according to FHWA recommendation. The FHWA also proposes using the rates of the Treasury inflation-protected securities to estimate the real discount rate. In addition, FHWA promotes the use of a probabilistic approach by means of the Monte Carlo simulation to account for the uncertainty in LCCA parameters. The probability distribution of the discount rate can be constructed as a triangular function with the parameters (ie, minimum, medium, and maximum) reflecting the probable range of the discount rate.

The FHWA as well as most guidelines on the choice of discount rate lays great emphasis on the use of a reasonable discount rate that reflects historical trends over long periods of time.

Synthetic Discount Rate: Philip Cady Proposition

Even though according to the LCCA survey (6) or the literature, there was no evidence that Cady's approach is actually practiced, it is included in this research for two reasons. First, it is clearly referred to as one possible approach for determining the discount rate in the open literature covering LCCA for highway investments (10). And second, it represents one of the approaches for determining synthetic discount rates as a policy tool.

Philip Cady proposed an alternate formula for the theoretical one (Eq. 3) for estimating the discount rate in the LCCA for highway construction in his paper titled "Inflation and Highway Economic Analysis" (9).

Cady's concept emerged from the situation manifested in the funding of highway maintenance and rehabilitation activities in 1985. This situation implicated rising highway construction costs and reduced revenues or funding. Cady postulates that the LCCA of highway construction must take these two detrimental effects into account (Cady). He derives a formula for estimating a synthetic inflation rate which he calls "pseudo-inflation rate: f^*". The "pseudo-inflation rate" then replaces the actual inflation rate in the real discount rate formula. (Eq. 3).

According to Cady's approach, the effect of rising costs can be estimated by the specific rate of inflation in the cost of the required services or industry (highway construction in this case), and the reduced funding effect is estimated by the annual rate change of highway funding. His "Pseudo-Inflation" rate is then derived and introduced by the following formula:

$$f^* = \frac{f' - q}{1 + q} \qquad \text{(Eq. 4)}$$

Consequently his real discount rate which he called the "true discount rate" is:

$$i^* = \frac{(1+i)(1+q)}{(1+f')} - 1 \qquad \text{(Eq. 5)}$$

Where :

f' is the specific inflation rate of the required services, highway construction in this case, *q* is the rate of change in highway funding and *i* is the nominal interest rate

State-of-the-Practice

The state-of-the-practice on how to choose and employ the discount rate was established using the results of two national surveys about LCCA practice in the transportation sector (6,10). In 1985, the discount rate used by SHAs ranged between 4 and 10%. In the year 2003 the discount rate employed by SHAs was between 3 and 5%, and sensitivity analysis was often conducted to examine the effects of the variability in the discount rate on the economic worth of the project.

Statistical Approaches

The deterministic approach has been employed traditionally in the analysis, even though the probabilistic approach is increasingly being favored and adopted (8,11,12,13). The deterministic approach ignores the inherent uncertainty of the discount rate and assumes discrete, fixed values for this rate—which results in a deterministic or point-estimate outcome. The probabilistic approach, which is sometimes referred to as risk analysis, uses probability distributions of uncertain input parameters and employs computer simulations to arrive at outcomes associated with the risks involved. Two techniques have been recommended in the literature (8,12) to be employed as a risk analysis approach namely, Monte Carlo simulation and Latin Hypercube simulation. Monte Carlo simulation is a technique that randomly samples the distributions that have been specified on the inputs to the model, and uses the model outcomes from the sampled values to produce a probability distribution of the output of interest. One drawback of Monte Carlo sampling approach is that it tends to select values from the areas in the distribution with a higher probability of occurrence. Therefore, many iterations will be required in order to ensure that sufficient samples have been taken to represent extreme or low probability, values. If a small number of iterations is performed, the output may lead to a 'clustering' of values around the high probability values. This problem can be overcome with Latin Hypercube sampling or stratified sampling. The Latin Hypercube approach involves dividing up the distribution into a number of strata,. To pick a value from the distribution, the simulator chooses a stratum at random, and then from within that stratum a random value is chosen. All the other strata are sampled from before the original stratum can be sampled again. Latin Hypercube sampling ensures that the whole distribution is covered much more quickly than in Monte Carlo sampling.

TABLE 1 The Eleven Scenarios for the Discount Rate

Scenario	Ref.	Statistical Approach	DATA	Parameters Employed in Estimating the Discount Rate				
				Real Interest Rate	General Inflation Rate	Nominal Interest Rate	Highway Construction Funding Rate	Highway Construction Inflation Rate
I	OMB Circular A-94	Deterministic	Long-term Treasury Real Interest Rate	✓				
II	FHWA-SA-98-079	Probabilistic – Latin Hypercube	Recorded Historic Rates	✓				
III	FHWA-SA-98-079	Deterministic	Average Historic Rates		✓	✓		
IV	FHWA-SA-98-079	Probabilistic – Latin Hypercube	Recorded Historic Rates		✓	✓		
V	Philip Cady's (1985)	Deterministic	Average Historic Rates			✓	✓	✓
VI	Philip Cady's (1985)	Probabilistic - Latin Hypercube	Recorded Historic Rates			✓	✓	✓
VII	FHWA-SA-98-079	Probabilistic-Monte Carlo	Recorded Historic Rates	✓				
VIII	Theoretical (Eq. 4.4)	Probabilistic – Monte Carlo	Recorded Historic Rates		✓	✓		
IX	Philip Cady's (1985)	Probabilistic – Monte Carlo	Recorded Historic Rates			✓	✓	✓
X	State-of-the-Practice	Deterministic	Assumption (Range of Values)	✓				
XI	FHWA-SA-98-079	Probabilistic – Monte Carlo	Assumption	✓				

ELEVEN SCENARIOS FOR THE DISCOUNT RATE

Based on the above probable practices on how to choose the discount rate (the source), how to calculate it (the parameters and the formulations), and how to employ it (the statistical approach and sampling type), we inferred eleven viable scenarios that the LCCA analyst in highway construction may adopt when deciding on the discount rate. These eleven scenarios, along with their details, are summarized in Table 1. Employing any of these scenarios may yield a different outcome of the LCCA.

The purpose of this research, is to study the implications of using each of these eleven scenarios on the decision support system so that a set of recommendations as to the best course of action to follow.

METHODOLOGY OF STUDY

The methodology of the study is based on a "look-back" analysis of the LCCA outcome resulting from the inferred eleven scenarios for the discount rate. It is accomplished in two steps:

- An ex-ante evaluation course: The LCCA is carried out to appraise the competing alternatives for the implementation of a project.
- An ex-post evaluation course: the life cycle cash flow of the project is established for the alternatives when implemented.

The results of the two courses are then compared and analyzed. One difficulty for the proposed methodology is the time frame needed to accomplish such a study if we were to take into account the actual monetary costs encountered throughout the life cycle of the project. If a real project is to be appraised and monitored through its life cycle, a minimum of fifteen years is needed to monitor the expenditure balance of the project—a provision that cannot be met in this research mainly because of the lengthy time required. We overcame this impediment by replicating the life cycle of a hypothetical project that took place years back and has reached the end of its life time. By employing the historical bona fide rates that are needed to accomplish the study—which are readily available and archived by government and private agencies—this replication should not have any effect on the credibility of the study.

The focal point in the study is that the ex-ante (prior to project implementation) and the ex-post evaluation (at the end of project lifetime) must make use of timely published data of the different interest, discount, inflation, and funding rates that are needed to have lifelike results. Furthermore, the case study is simplified so that only the consequences resulting from the use of different approaches for the discount rate can be observed.

SIMULATING THE SCENARIOS

Suppose by the end of 1984 New Jersey DOT had to choose between two strategies for one project as illustrated in Figure 1.

- In strategy A, the project involves an initial single action costing $100,000; its lifetime is expected to be fourteen years.
- Strategy B involves an initial action costing $60,000; its lifetime is expected to be seven years—after which the same action has to be repeated. Also, similar to strategy A, there is no annual maintenance or other operational expense.

The LCCA as a measure of cost-effectiveness is used to appraise the two possible strategies; the project with the lowest net present value (NPV) is the preferred choice. The general

LCCA model is reiterated for ready reference.

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad \text{(Eq. 6)}$$

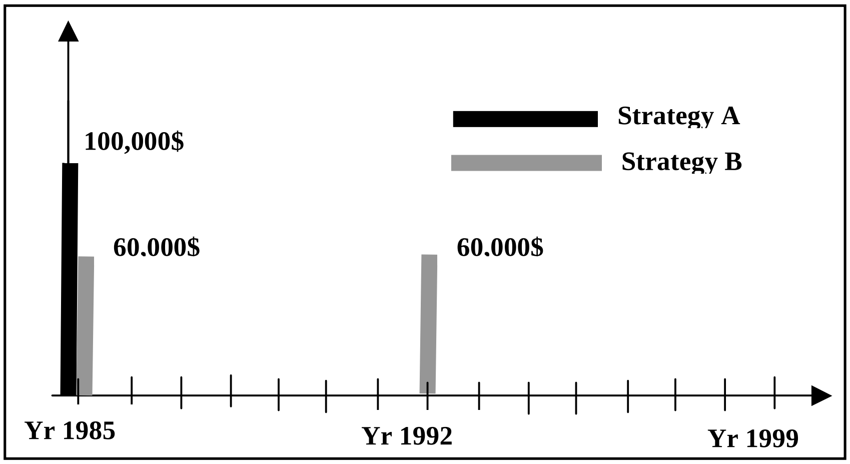

FIGURE 1: Expenditure Stream for the Two Alternatives in Real Dollars 1985

The Data Sources

The data needed to calculate the different discount rate scenarios is gathered from a number of sources, depending on their nature:

- US Highway Statistics, New Jersey DOT, The US FHWA
- The Federal Reserve Bank ,The US Office of Management and Budget

The inflation in highway construction and the rate of funding were calculated as the annual proportionate-change-in-highway-construction price index and the total disbursement for highway construction respectively for all the years in the lifecycle of the project between year1970 and year 2000—Figure 2.

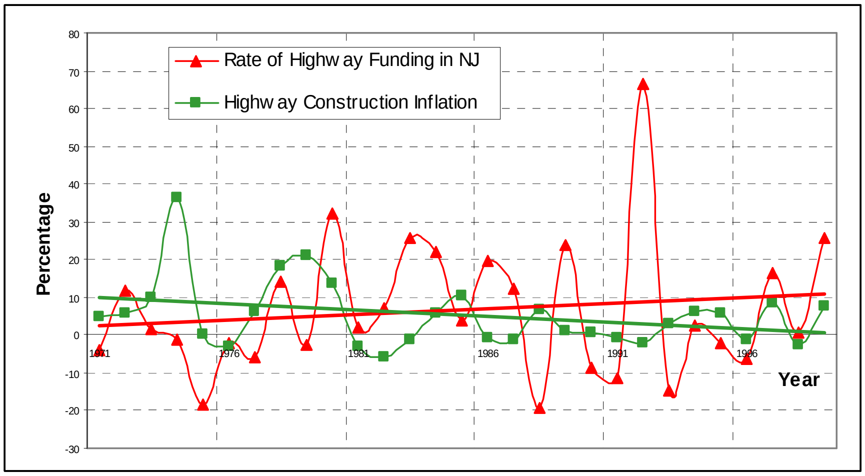

FIGURE 2: Rate of Highway Funding in NJ and Highway Construction Inflation (1971-2000)

TABLE 2: Input Parameters Employed in Estimating the Discount Rate in the Eleven Scenarios

Scenario	Parameters employed in estimating the Discount Rate				
	Real Interest Rate Input 1	**General Inflation Rate Input 2**	**Nominal Interest Rate Input 3**	**Highway Construction Funding Rate Input 4**	**Highway Construction Inflation Rate Input 5**
I	6.1	N/A	N/A	N/A	N/A
II	Lognorm (0.07, 0.07, Shift(-0.02), Truncate(0, 0.25)	N/A	N/A	N/A	N/A
III	N/A	7.34	9.14	N/A	N/A
IV	N/A	Extvalue (5.8441, 2.5487, Truncate(0, 25)	Lognorm (4.0735, 3.1745, Shift(5.1191), Truncate(0, 25)	N/A	N/A
V	N/A	N/A	Lognorm (4.0735, 3.1745, Shift(5.1191), Truncate(0, 25)	Extvalue (-0.0037391, 0.11441, Truncate(-0.3, 0.6)	Extvalue (2.8517, 8.0177, Truncate(-15, 50)
VI	N/A	N/A	9.14	5.92	7.76
VII	Lognorm (0.07, 0.07, Shift(-0.02), Truncate(0, 0.25)	N/A	N/A	N/A	N/A
VIII	N/A	Extvalue (5.8441, 2.5487, Truncate(0, 25)	Lognorm (4.0735, 3.1745, Shift(5.1191), Truncate(0, 25)	N/A	N/A
IX	N/A	N/A	Lognorm (4.0735, 3.1745, Shift(5.1191), Truncate(0, 25)	Extvalue (-0.0037391, 0.11441, Truncate(-0.3, 0.6)	Extvalue (2.8517, 8.0177, Truncate(-15, 50)
X	Range (1%-9%)	N/A	N/A	N/A	N/A
XI	Triang(2,6,10)	N/A	N/A	N/A	N/A

Using the gathered data and employing equations 3, 4, and 5, the input data of the eleven scenarios of the discount rate is prepared as shown in Table 2 below. The historical data used to calculate the discount rate input parameters and their respective best-fit probability distributions in the LCCA model go back to the period between 1970 and 1984. This period is equal to the life time of the project before 1985—at the point in time when the ex-ante evaluation occurs. The cost input parameter C_t and the timing of activity (t) were treated as certain parameters in all scenarios when conducting the LCCA (5).

TABLE 3 The LCCA Outcome under the Different Discount Scenarios

Scenario	Reference	Statistical Approach	NPV Alternative A ($1000s)	NPV Alternative B ($1000s)			Probability NPV B < NPV A
				Value	Mean	Standard Deviation	
I	OMB Circular A-94	Deterministic	100	99.641			Yes
II	FHWA-SA-98-079	Probabilistic – Latin Hypercube	100		107.124	11.9686	26.28
III	FHWA-SA-98-079	Deterministic	100	111.196			No
IV	FHWA-SA-98-079 (Cal.)	Probabilistic – Latin Hypercube	100		115.573	15.73	12.39
V	Philip Cady's (1985)	Deterministic	100	96.717			Yes
VI	Philip Cady's (1985)	Probabilistic - Latin Hypercube	100		127.61	89.47	51.67
VII	FHWA-SA-98-079	Probabilistic-Monte Carlo	100		107.78	12.19	26.40
VIII	FHWA-SA-98-079	Probabilistic-Monte Carlo	100		115.78	16.00	11.55
IX	Philip Cady's (1985)	Probabilistic Monte Carlo	100		125.59	87.88	51.48
X	State-of-the-Practice	Deterministic	100	92.822 – 115.963			N/A
XI	FHWA-SA-98-079	Probabilistic Monte Carlo	100		100.226	4.27	49.63

The simulation, whether it was using Monte Carlo Sampling or Latin Hypercube, was repeated several times for each scenario with different seed values; the resulting mean and the standard deviation differ slightly—not surprisingly—at each simulation, but the estimated probabilities of the risk associated with the final LCCA outcome (if the NPV of strategy B is higher than the NPV of strategy A) maintained the same level in all simulations performed. The simulation parameters employed 1.5% auto-stop simulation convergence rate with the seed chosen randomly. Latin Hypercube simulations resulted in 1800 iterations before convergence in 6 seconds whereas Monte Carlo simulations converged at 2700 iteration in 11 seconds.

The LCCA results using the eleven scenarios for the discount rate are illustrated in Table 3. Figures 3 and 4 illustrate the cumulative probability distribution of the NPV of alternative B under the probabilistic scenarios and Figure 5 illustrates the sensitivity analysis of both alternatives in X.

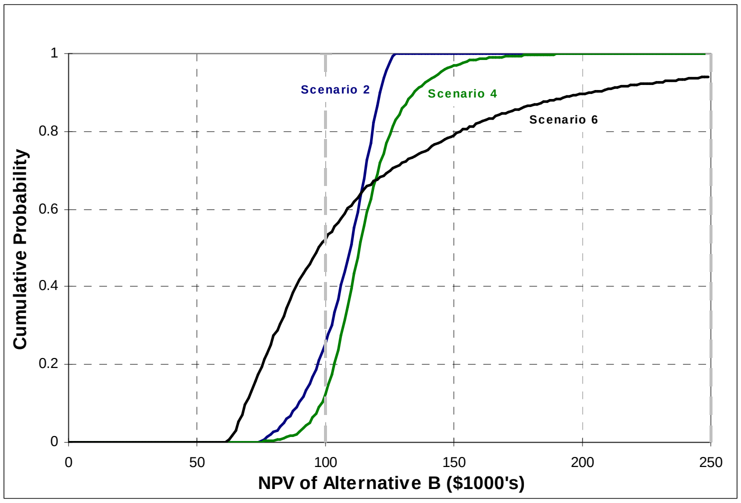

FIGURE 3 Cumulative risk profile for NPV of B under different scenarios (Latin Hypercube)

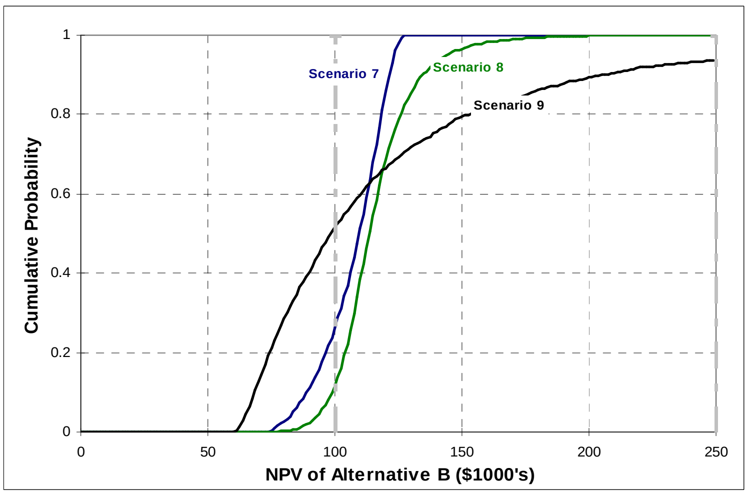

FIGURE 4 Cumulative risk profile for NPV of alternative B under different scenarios (M.C.)

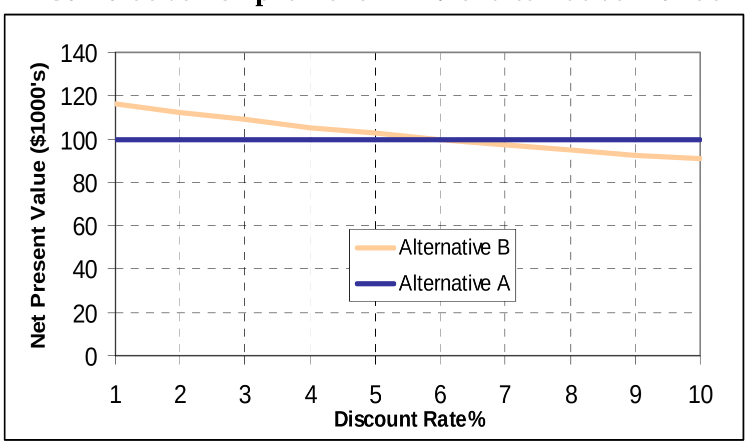

FIGURE 5 Sensitivity analysis of the discount rate on the NPV - Scenario X

THE REAL COST OF EXAMPLE PROJECT: EX-POST EVALUATION

The ex-post evaluation course was pursued via reconstructing a time line of expenditure in line with what actually might have happened, assuming there was a surplus of $200,000 in the general fund that financed the hypothetical project. Surpluses in the general funds are typically invested in short-term securities. Thus, acquiring the interest rates applied for 3-months CD from the Federal Reserve Board for every three month period in the project's lifetime of fourteen years and calculating the compounded interest of the surplus balance in both cases, we determine the costs of strategies A and B.

The time line of expenditures is shown in Table 4, in which the values represent the actual would-be balance at the beginning of each year (eg, The actual balance sheet is estimated every three month, but only the summary Table is presented). The balance values in the table represent the balance in the previous year plus the interest gained from investing in 3-months CD plus or minus the transaction (payment or deposits) resulting from the implementation of the project.

The second action in strategy B is assumed to take place at the beginning of 1992 as was planned. The cost of this action is inflated by using Eq. 6 where the price index of highway construction is the appropriate indicator of the nominal price of the action in 1992 (4).

$$COST(1991) = \frac{HCPI(1991) - HCPI(1985)}{HCPI(1991)} * COST(1985) \quad \text{(Eq.6)}$$

where HCPI is the Highway Construction Price Index.

TABLE 4 The Current Time Line Expenditure of Strategy A and B

Year	Strategy A		Strategy B	
	Transaction	Balance	Transactions	Balance
		200000		200000
1985	-100000	100000	-60000	140000
1986		108198		151477
1987		114987		160982
1988		123298		172617
1989		133598		187037
1990		145840		204177
1991		157765		220871
1992		166383	-69654	163283
1993		172207		168997
1994		177713		174401
1995		186991		183507
1996		198007		194317
1997		208984		205090
1998		220990		216872
1999		**$232977**		**$228636**

The last row in the time line of expenditure in Table 4 shows the balance at the end of the project lifetime. Accordingly, if strategy A were chosen, the balance would be $232,977; if strategy B were chosen, the balance in the general fund would be $228,636.

Comparison Between ex-ante against ex-post evaluation

To be able to compare the results of ex-ante against ex-post evaluation courses, the project's total cost in both courses must be converted to a common timeframe. Calculating the NPV (year 1985) of the difference between the 1999 project's cost for both strategies A and B (the last row in Table 4) by employing the recorded interest rates, yields a value of $1,850, indicating that the estimated NPV of B is $101,850. Thus, strategy A had a smaller NPV and should have been the favorable alternative. At this point, it is possible to compare this result with the results listed in Table 3 for the eleven scenarios in the ex-ante evaluation.

ANALYSIS OF RESULTS

Examining the ex ante evaluation versus the ex post evaluation results of the project strategies, we rate the scenarios employed in relation to how acceptable outcome was. The rating is based on three elements—the mean, the standard deviation, and the probability associated with the outcome; bearing in mind that LCCA is basically performed to provide informed support for the decision-making process. The requisite is to have a mean as close as possible to the actual NPV, a small standard deviation, and an estimate of the probability of occurrence that can facilitate the decision making processes:

Category A: Scenario II, VII, XI

This group provided good results in the mean value, in the standard deviation, and in quantifying the probability associated with the outcome.

Category B: Scenario I, IV, VIII, X

This group provided acceptable results in the mean but was unable to quantify the probability of occurrence properly.

Category C: Scenarios III, V, VI, IX

This group was unsuccessful in arriving at acceptable results when looking at the point estimate, the mean, the standard deviation, or the probability when applicable.

Before analyzing the results further, it must be noted that this hypothetical project was chosen because the NPV of the alternatives were intentionally very close; otherwise, when the difference is more than 20%, the sensitivity of the discount rate is not significant for the final outcome anymore.

Based on the information above, we observe the most appropriate results are arrived at by employing a probability distribution for real discount rate that is constructed from the results of the real discount rate as estimated annually from the long-term maturities rates for the nominal interest rate and the general inflation rate.

The statistical approach is better employed probabilistically using simulation. Even though both types of sampling, Monte Carlo and Latin Hypercube, arrive at almost similar results, the Latin Hypercube saves time, as anticipated, especially when the model has a larger number of uncertain parameters and more complicated computations.

According to our exercise, Cady's synthetic rate approach (scenario V,VI, IX) appears to be unfavorable due to three major shortcomings.

- First: in general, economic analysis literature warns against predicting future values based on past historic trends during times of recession or unusual conditions. Cady's approach was developed in 1982 by considering conditions of reduced highway funding and increased highway construction costs during that specific time period (9). Figure 6 illustrates the timely trend in the federal aid highway construction prices and the consumer prices index. The trend of increasing highway prices during the seventies is quite clear from this data. This situation occurred under the unusual economic times of the oil embargo, along with other entailing consequences. As such, decisions regarding highway investment should not be based on analysis that reflects such unusual conditions. This unusual trend was clearly reversed later during the eighties.

To validate this point further, going back into the basic assumptions behind deriving Cady's synthetic rate, which combines decreasing rates in highway funding and increasing highway construction prices, we examined rates of change in highway funding in New Jersey and the highway construction inflation from 1971 to 1999 (illustrated in Figure 6). Our observations indicate that the basic assumptions of Cady did not actually hold in the period after he developed his formula in 1985. In fact if we consider that during time the period between 1971 and 1999 the trends in these two parameters behave exactly opposite to what Cady assumes. This can be clearly seen in the slopes of the trend-lines corresponding to those rates.

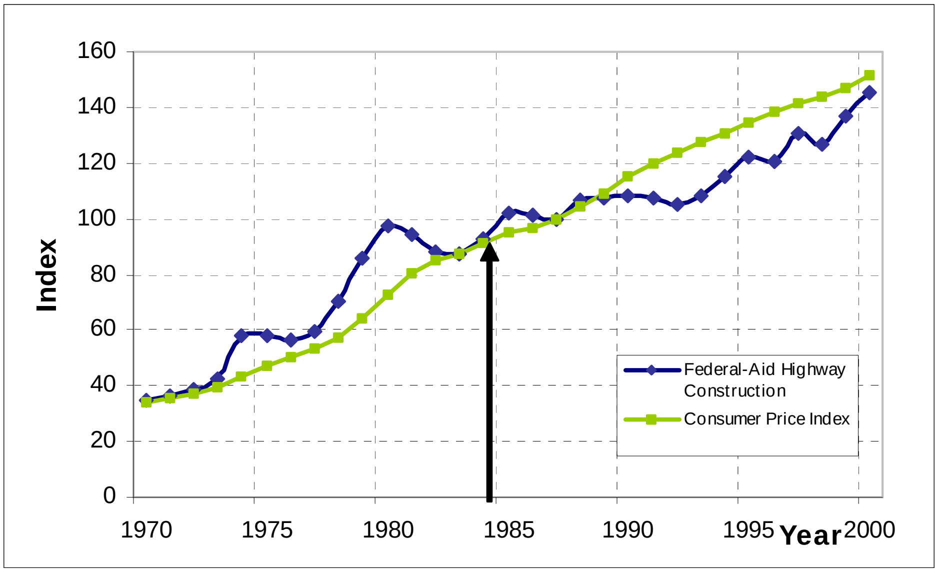

FIGURE 6 Consumer Price Index and Federal-Aid Highway Construction Price Index

• Second, Cady's approach of calculating the pseudo-inflation is based on two factors—namely, the reduced rates of highway funding and the rate of change of highway construction prices. Predicting the future trends of these two highly uncertain rates adds greatly to the overall uncertainty of his results. This is demonstrated clearly by the large range of variability in the example results when employing this approach and is quite evident from the tornado graph in Figure 7, which illustrates the correlation sensitivity of the uncertain parameters when employing Cady's approach probabilistically. Since the economic analysis is intended to serve as a decision support tool, presenting outcomes associated with high risks can only distort the decision making process.

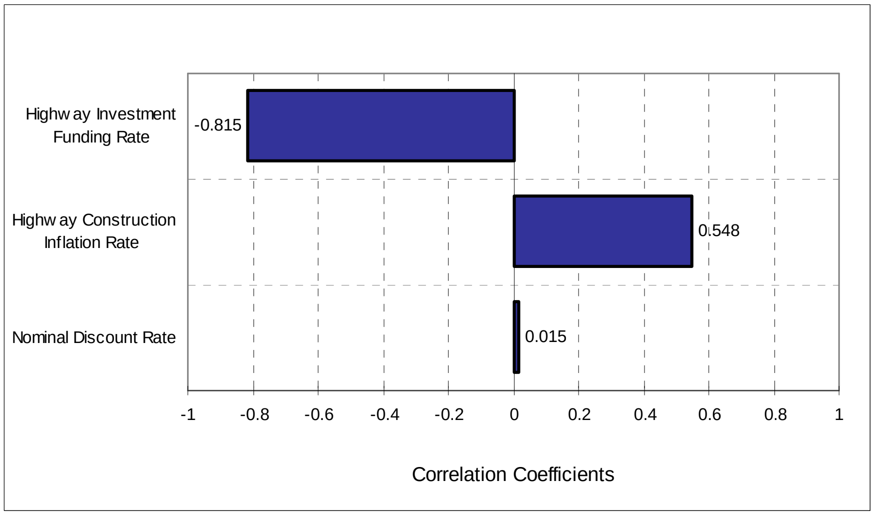

FIGURE 7 Tornado Graph of the Correlation Coefficient in Scenario

- The third point examines exhaustively if the intended objective of deriving the synthetic discount rate can be actually achieved at all times provided Cady's assumptions stand. In other words, does the synthetic discount rate demonstrate steady behavior in relation with its objective? Since his discount rate is introduced as a policy tool to account for conditions of reduced funding and increased highway construction inflation, one would assume that the premeditated policy should favor investments with higher upfront costs. This can be achieved when the synthetic discount rate is lower than the conventional discount rate, assuming that only agency costs are included in the analysis. The synthetic discount rate based on Cady's approach, however, exhibits inconsistency in the results attained, is economically unjustifiable. Assume a case where the nominal interest rate is 10% and the general inflation rate is 7%; if the funding rate was 1% (low rate as Cady assumes) and the highway construction inflation rate was 8% (higher than the general inflation rate), the real "conventional" discount rate as calculated by equation 3 would be 2.8% while the pseudo inflation would have a higher value of 2.9%. This result reverses his intended objective. Figure 8 shows that when the construction inflation rate is between 7% and 8%--which is our assumed general inflation rate—the synthetic discount rate is actually higher than the standard calculated discount rate. This phenomenon can be observed using other combinations of interest and inflation rates. For most combinations, there appears to be some critical range where the synthetic discount rate reverses its anticipated action with no justifiable grounds.

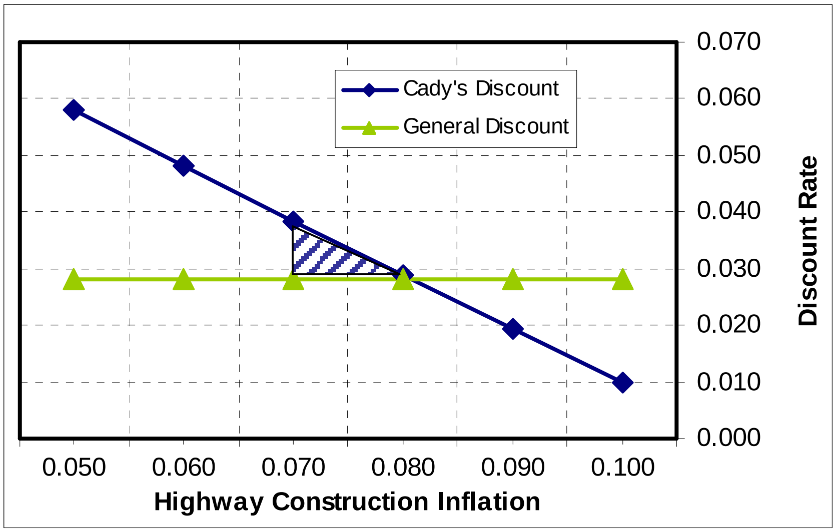

FIGURE 8 Cady's Discount Rate and the Conventional Discount Rate against Highway Inflation assuming General Inflation of 7% and Nominal Interest of 3%

CONCLUSIONS

When estimating future costs of transportation projects, discount rates play an important role. The traditional approach of using a fixed average discount rate for long-term monetary cost estimation can skew the accuracy of estimates. It is also clear that discount rates are subject to fluctuation over time due to many reasons. This paper attempts to advance the state-of the-art for cost estimation by investigating probabilistic approaches based on reliability concepts.

As shown in the discussion presented in this paper, probabilistic approaches based on reliability concepts are best suited for conducting analysis where there is some inherent uncertainty in the variables. Such approaches provide valuable support for the decision-making process by accounting for the risks associated with the analysis outcome through the estimation the probabilities of occurrences. Then again, including pointless variability in the parameters results in an outcome that spreads over wide ranges. Such analysis outcome would actually make the decision-making process more difficult—if not impossible—instead of serving as a valuable support tool. Conducting sensitivity analysis for each parameter separately can provide a scheme for identifying unnecessary variability and thus preventing such situations.

On the other hand, any synthetic calculation of discount rates that aim at formulating policy tools for conducting the economic analysis of future public investments based on unusual historic conditions should be considered as unfavorable. In this paper, we specifically showed that one such approach namely, synthetic discount rate based on Cady's approach, exhibits inconsistency in the results attained and thus it is economically unjustifiable. Caution must be taken in identifying such conditions to prevent unrealistic analysis outcomes. Furthermore, these synthetic rates should be tested for complete consistency in achieving the policy objectives.

The analysis presented in this paper points to two credible options for modeling the discount rate: 1) a probability distribution constructed from the past recorded real treasury discount rate in OMB circular A-94 from 1979-2003 corresponding to 30-year maturity. However, special attention must be given for the distribution bounds, and 2) a triangular distribution constructed with the point estimate value of the real treasury discount rate in the evaluation year as the mid point and with +/- 2% as the min and max boundaries of the distribution.

Some of the simple guidelines for the practitioners can be as follows:

1. Avoid using fixed average discount rates that cannot be justified in the light of historical data.
2. Avoid using untested discount rate estimation equations similar to Cady's equation that are not based on robust economic theory. In fact, these equations can generate more erroneous results than fixed average values.
3. Use probabilistic approaches that are based on distributions estimated using historical data. In fact, in the economics area, this data is abundant and reliable. The most important roadblock that impedes the usage of probabilistic methods is the lack of understanding of basic concepts by practitioners. Simple but comprehensive guidelines have to be developed.

In the future, more studies have to be conducted using historical data from various real-world projects to further analyze the effect of using fixed average discount rates versus discount rates estimated using approaches similar to the ones proposed in this paper.

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