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Valuation techniques for infrastructure investment decisions

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Public infrastructure owners are increasingly soliciting BOT arrangements to deliver needed infrastructure facilities. Such arrangements potentially preserve a public owner's capital capacity for allocation to projects that cannot support themselves by essentially 'pulling' projects from the private sector. Before soliciting these arrangements, however, owners should independently evaluate a project's economic viability to fully appraise the issues and variables involved. Unfortunately, project analysts often apply evaluation methods without regard for their assumptions and limitations. A case study of a toll road project in the USA provides the basis for examining the assumptions behind both traditional and option valuation models. The case demonstrates the use of an option pricing model to augment traditional project evaluation by capturing strategic considerations, in this case the value of project deferment. The presentation illustrates that the selection of a valuation model depends critically upon the characteristics of a project's variables and that informed judgment remains an integral part of the decision-making process.

Keywords: Valuation techniques, infrastructure investments, real options, risk neutrality

Introduction

The requirements to expand, modernize and sustain infrastructure facilities amidst dynamic changes and capital constraints worldwide are well known, and these conditions have forced public infrastructure owners to adopt innovative methods to provide the facilities and services necessary to support economic productivity and social welfare. Build-operate-transfer (BOT, Aka DBFO) has been resurrected as one viable strategy to deliver needed capital facilities. Tolled highways are but one type of project where the potential for non-recourse, asset-based financing exists. Such arrangements can potentially preserve a public owner's capital capacity for allocation to projects that cannot support themselves by essentially 'pulling' projects from the private sector. Within the USA, existing procurement statutes and regulations effectively restrict public owners from freely adopting alternative delivery strategies, but the writers foresee a future where an open environment exists for owners to choose the path of delivery for a capital facility.

In this environment, it is incumbent upon the owner to properly evaluate a project's potential for non-recourse project financing before requesting proposals from private vendors. Evaluating the economic viability of such projects from the perspective of potential investors forces a public owner to independently consider the market risk. Aside from assessing a project's economic viability, this evaluation also gives an owner the opportunity to explicitly consider whether: (a) the user rates needed to provide an adequate return on an asset are politically acceptable and (b) the returns are strong enough to permit private financing at borrowing rates which are comparable with the owner's rate. Both outcomes are important determinants for proceeding with a BOT delivery strategy.

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Economic feasibility analysis has not traditionally been a skill widely harboured by public leaders or engineering professionals. Of course, engineering economics literature and curriculum provide the 'mechanics' of economic evaluation, but they are generally devoid of substantive discussion about techniques for selecting a discount rate (or minimum attractive rate of return). The discount rate is the most important factor influencing an asset's economic tractability when applying traditional valuation methods. In addition, many infrastructure investments possess option-like features such as deferment or staged investment that traditional valuation methods cannot represent, so quantifying the value of such options can be quite significant to the timing of investments.

Given these circumstances, the intent of this paper is to present, illustrate and discuss methods for valuing private investments in public infrastructure. The first portion of the paper provides an overview of valuation methods in the context of infrastructure development, with an emphasis upon exposing and discussing underlying assumptions. The second portion illustrates particular valuation techniques through a retrospective case study of a toll road development project in the USA. The paper concludes with a discussion of pertinent issues highlighted by the case study.

Traditional valuation

Discount rate selection

The use of discounted cash flows (DCF) to determine net present value (NPV) is the preferred method for establishing the value of a project that is not set in an active market, such as infrastructure projects (Finnerty, 1996; Grinblatt and Titman, 1998; Brealey and Myers, 2000). An asset's economic viability determined by NPV analysis is most sensitive to the discount rate. Despite this sensitivity, discount rate selection remains elusive even for seasoned financial analysts. For market-driven investment decisions, the discount rate should represent the risk of the asset in question by replicating the return that investors would require from assets of similar risk (Brealey and Myers, 2000). This aspect of the discount rate is commonly misunderstood, and a firm's opportunity cost of capital is mistakenly chosen to discount future cash flows. This can result in the rejection of projects with risks less than or the acceptance of projects with risks greater than those appropriate for the firm's discount rate.

Traditional valuation regularly employs the weighted average cost of capital (*WACC*) to estimate the discount rate:

$$WACC = R_2e * (E/V) + R_2d * (D/V) * (1 - t) \quad (1)$$

where R_e is the required return-on-equity, R_d is the cost of debt, and t is the marginal tax rate. E and D represent levels of equity and debt financing respectively, which sum up to V, the total capital invested. Typically, the *WACC* represents a company's cost of capital, and it is employed to evaluate projects that match a firm's existing operating assets and associated risks. Thus, determining R_d, t, D, E and V is not terribly difficult, and the last variable, R_e, is often estimated by the well-known capital asset pricing model (CAPM):

$$R_e = R_f + \beta_e (R_m - R_f) \quad (2)$$

Each value in Eq. 2 can be derived empirically from market data.

Infrastructure projects, however, are not actively traded in secondary markets, so estimating a discount rate for such projects is more problematic. One approach is to identify proxies for each variable. For instance, values for R_d and D can often be derived from similar project financing schemes of comparable risk, and then a value for E can be backed out from the total project investment required ($E = V - D$). Still, determining an appropriate value for β_e of an infrastructure project can be quite a challenge.

In lieu of the first approach described, Brealey and Myers (2000) suggest an alternative method that utilizes Eqs 3 and 4:

$$\beta_a = \beta_{revenue}[1 + \mathrm{PV(fixed\ cost)/PV(asset)}] \quad (3)$$

$$R_a = R_f + \beta_a (R_m - R_f) \quad (4)$$

These equations require an analyst to first assess an asset's cyclicality and operating leverage to derive an approximation of the asset's sensitivity to market movements (β_a), and then to utilize this value along with empirically determined estimates of the risk-free rate (R_f) and the market risk premium ($R_m - R_f$) to arrive at a discount rate (R_a).

$\beta_{revenue}$ is a measure of dependence between a project's revenues and economic cycles. Higher dependence between project revenues and the general state of the economy will keep $\beta_{revenue}$ close to 1. A reasonable proxy for the ratio of [PV(fixed cost)/PV(assets)] is the ratio of [(fixed cost)/(earnings before interest & taxes or *EBIT*)] for the project of interest. This proxy ratio should be estimated using projections in a project's maturity when operating leverage becomes relatively stable. If an analyst has difficulty estimating these values, similar past projects can be identified to assist in making such judgments. Clearly, this second approach is more subjective, but in the absence of project or market data, it provides an analyst with an alternative technique for deriving an estimate of the discount rate.

Limitations of traditional valuation

NPV analysis works quite well when the risks across the lifespan of an asset remain relatively stable. Luehrman (1997) and Myers (1984) suggest that traditional valuation methods are adequate for investment decisions regarding assets-in-place. In such cases, ongoing operations generate relatively safe cash flows and are held for this reason, not for less tangible strategic purposes. Traditional valuation also works well for typical engineering investments, such as equipment replacement, where the main benefit is cost reduction. Investments, however, often create future growth opportunities (e.g. follow on development if product demand is favourable) or they have contingency possibilities (e.g. delay or abandon project). In effect, the risk of subsequent cash flows can change as development proceeds or new information is received. In such cases, DCF methods understate the value of this flexibility, and Amram and Kulatilaka (1999), Trigeorgis (1999), Dixit and Pindyck (1994), Myers (1984), and others point to this shortcoming.

In fact, infrastructure development often proceeds in a series of stages that aim to better define project scope and discover unknown information. Moreover, flexibility is often incorporated as an intuitive managerial approach to deal more effectively with uncertainty. Preliminary planning and feasibility studies, such as environmental impact studies, geotechnical surveys and traffic volume analyses, can reveal information that may alter further investment and development decisions. Flexible design permits infrastructure projects to more readily adapt to changing conditions, such as an increase or decrease in expected demand for the project's output. Staged construction can afford decision-makers the opportunity to gain more information as market conditions become more certain. In short, flexibility can effectively reduce life cycle costs by allowing a timelier and less costly response to a dynamic environment. Flexibility adds value, but it comes at a cost in terms of money, time and complexity. This added value should be weighed against its cost, but traditional valuation methods do not adequately support such analyses.

Real option models

Real option models and alternative valuation techniques have been proposed and developed to address traditional valuation's limitations. In general, real option models fall into two categories: continuous-time models and discrete-time models. Depending on the particular context of application, the two approaches incorporate different assumptions, which ultimately determine the suitability of the selected model. The following sections emphasize the differences between continuous-time and discrete-time models and the resulting implications of real option modelling techniques in construction and infrastructure projects.

Continuous-time models

Continuous-time models represent one or more variables as stochastic processes. For infrastructure projects, analysts often select the value of the underlying facility, which is the present value of cash flows derived from the completed project or specific operating assets, as the variable of interest. Occasionally, analysts may decide to model cash flow components at a more detailed level, so the value of the underlying project/asset is further decomposed into variables such as price, costs (both operating and construction) and volume/quantity. Understandably, most continuous-time models are restricted to just one or two variables due to computational complexity.

The change in value of the variable of interest (denoted as dV) can be modelled by the generalized Weiner process, a fundamental stochastic process with the following form:

$$dV = \mu dt + \sigma dz \tag{5}$$

On the right-hand-side of Eq. 5, the first term is the expected drift, or a 'slope' parameter for a graph plotted with V on the vertical axis versus time on the horizontal axis. This 'slope' parameter sets the average rate of change in long-term value. Short-term fluctuation in value evolving around the slope, usually referred to as 'volatility', is modelled by the second term, σdz. By itself, dz represents the basic Wiener process:

$$dz = \varepsilon \sqrt{dt} \tag{6}$$

where ε is a random variable with a standardized normal distribution ϕ (0,1). Essentially, this is the Brownian motion from physics that readers are probably familiar with. The σ parameter, then, is a scaling factor or variance rate that controls the extent of volatility.

Further modifications can be introduced to Eq. 5 when the drift and variance rates become functions of the underlying variable and time. Known as the Ito process, this is mathematically represented by:

$$dV = \mu(V,t)dt + \sigma(V,t)dz \tag{7}$$

Eq. 7 is a more practical model since in many circumstances the drift and variance rates of the variable of interest are unlikely to remain constant over time.

In finance, a favourite form of Eq. 7 is the geometric Brownian motion that treats both the drift and the variance terms as being proportional to the variable V:

$$dV = \mu V dt + \sigma V dz \tag{8}$$

For real option modelling, however, a word of caution is warranted. A property inherent within this form of mathematical representation is that the variable V is log-normally distributed. Before applying this process to the selected variable, one should question whether it is correct to assume that the variable approximately follows a lognormal distribution. For example, if the traffic volume of a toll road, at some point in time, does not follow a lognormal distribution, then its stochastic evolvement should not be modelled with Eq. 8. Other forms of stochastic processes exist to broaden the regime of stochastic process modelling under different scenarios due to peculiar characteristics or distribution of the underlying. These include the mean-reverting process and the Poisson jump process. Detailed mechanics of these stochastic processes can be found in Dixit and Pindyck (1994), Hull (2000), McDonald (2002) and Wilmott (1998).

In continuous-time models, solving for the value of a real option contingent on variables such as V often requires the derivation of a partial differential equation (PDE). The procedure then transforms from an intuitive consideration of strategic issues into mathematical manipulation where the PDE is solved subject to a set of boundary conditions related to the features of the option. In the best case, a closed-form solution exists for the PDE, thus allowing it to be solved analytically. The Black-Scholes equation used to evaluate a European option is a good example (Hull, 2000). Pindyck (1991) provides another example of an analytical solution for the simplest version of an investment timing problem.

When the PDE does not have an analytical solution, one has to resort to numerical methods. Finite-difference schemes, both implicit and explicit forms, are commonly used. Comparisons between these two forms (e.g. in terms of robustness, convergence, computational efficiency) have been widely discussed and need not be repeated here. A point worth mentioning, however, is that some researchers, such as Brennan and Schwartz (1978) and Hull and White (1990), have developed and published algorithms that will simplify and improve the valuation procedures using finite difference methods.

Another popular numerical procedure is the Monte Carlo simulation technique that simulates thousands of sample paths for a variable based on its stochastic process. For example, by taking random draws of ε in Eq. 6, sample paths for variable V can be simulated by substituting Eq. 6 into Eq. 7 with a predetermined time-step Δt. Evaluation is especially simple for a European option, where exercise of the option is only feasible at maturity, as illustrated in McDonald (2002). Real options, however, are often more akin to American options (or even compound options) in which optimal option exercise can happen before maturity. In other words, unlike the evaluation of a European option that resembles a forward induction procedure, values of real options in these situations often become path- and state-dependent, thus requiring a backward induction procedure. As with finite difference schemes, recent research has worked towards incorporating the features of backward induction in Monte Carlo simulation (Barraquand and Martineau, 1995; Broadie and Glasserman, 1997).

Discrete-time models

Common forms of discrete-time models include the binomial model, the trinomial model and the lattice model. Many of these models have been developed with an intention to provide an approximation to continuous-time models ‘in the limit’. For example, for a binomial model, Cox *et al.* (1979) recommended values for the up and down movements of the underlying variable V so that its volatility matches that of the stochastic process given in Eq. 8 in the limiting situation. Boyle (1988) further expanded this approach for a trinomial and a lattice model while recommending appropriate jump magnitudes and associated probabilities. Thus, the underlying assumptions for this first category of discrete-time models and their continuous-time counterparts are basically the same. They are conceptually equivalent – but they are solved using different mathematical approaches.

Discrete-time models need *not* be mere approximations of their continuous-time counterparts, hence giving rise to what the writers consider as the second category of discrete-time models. This class of models essentially represents ‘economically corrected’ versions of decision-tree analysis so that the problems of payoff structure, risk characteristics and non-constant discount rates – all of which are primarily due to the flexibility and asymmetry embedded in the decision-making process – can be overcome (Trigeorgis, 1999). This is done by converting the real situation into a risk-neutral one. More importantly, due to its resemblance to traditional decision-tree analysis, managerial flexibility can be modelled more explicitly in the tree structure. Consequently, modelling real options in this way is more intuitive. When simply imposing stochastic processes on underlying variables cannot represent a real option scenario, this approach is especially valuable. In fact, the case example presented subsequently provides an example of such a model.

Implementation & application issues in infrastructure development

Two recent publications in this journal illustrate the differences in modelling real options in infrastructure development and construction. Ho and Liang (2002) adopted a discrete-time approximation to model the stochastic processes of two log-normally distributed variables, project value and construction cost, to subsequently solve for equity value using a lattice model. Ford *et al.* (2002) used a binomial option pricing approach to quantify the value of design flexibility; their method is closer to the framework of an 'economically corrected' decision-tree analysis – the second category of discrete-time models described previously. While Ho and Liang's valuation is mathematically more elegant, Ford *et al.*'s application is a more intuitive and flexible model for specific construction scenarios.

The appropriateness of each model and approach depends on the particular context of application, which in turn dictates the validity of the assumptions underlying each model. Obviously, Ho and Liang's assumptions are rather strong since project value and construction cost may not follow lognormal processes. If one considers an equity investment in the construction of a power plant or exploration of an oil field, however, utilization of a continuous-time model, with the output following a specific stochastic process, can indeed be a reasonable approach. Market prices for the output of these projects are given in the spot and future/forward markets, so historical data can be used to determine the most appropriate stochastic process to model the underlying asset. For example, Wey (1993) found that crude oil prices are likely to follow a mean-reverting process for a long time horizon, and evaluation of a real option contingent on oil prices could be modelled with this consideration in mind.

The same contention, however, would not hold for a toll road project. Arguing that traffic volume (and hence toll revenues) follows a geometric Brownian motion evolvement or a mean-reverting process is quite a stretch. Perhaps, a stochastic process that incorporates multi-stage growth with jumps would better represent the evolvement of traffic volume, but its mathematical complexity might not warrant the effort needed once all the required assumptions are made. For this reason, an analyst should probably look for ways to represent the traffic growth scenario in terms of a decision tree, but using the risk-neutral option pricing technique for evaluation so that it is 'economically corrected' and captures asymmetry and flexibility.

Another application issue is the assumption of risk-neutrality (i.e. risk preference does not matter), which is often essential in real option evaluation. Risk-neutrality is a common feature inherent in most option-pricing models; even the original derivation of the Black-Scholes-Merton differential equation has this feature (Hull, 2000). Flexibility and asymmetry in option payoff imply a changing discount rate when the option progresses towards expiration, thus rendering discounted cash flow methods inadequate. Assumption of risk-neutrality overcomes this problem by transforming the actual setting into a risk-neutral world, which has the following characteristics:

- Risk preference and the expected return of the underlying asset do not enter the equation, and all assets will appreciate at the risk-free rate in this world. Consequently, a *single* risk-free rate can be used to discount cash flows in all periods.
- Even after transforming the problem from the real to a risk-neutral world, volatility of the underlying asset itself stays the same; therefore, uncertainty of the project is still captured in the evaluation process.

The above results are achieved by transforming probability measures from the actual probability function into a 'risk-neutral probability function'. Technically, this change of measure is an illustration of Girsanov's Theorem (Mikosch, 2000).

Though important and often necessary to be applied, risk-neutrality should not be taken lightly as a rule without first understanding its assumptions. The main assumption behind risk-neutrality is that the market is complete, so that a tracking portfolio can be found among traded assets, which allows replication of the cash flow from the option (a form of the 'no arbitrage' principle). When movement of the underlying asset is spanned by a complete market, options can be valued as if investors are risk-neutral, since other assets are available for them to hedge the uncertain cash flows. When initial value for a project and market prices of the underlying are unknown or difficult to estimate, however, a risk-neutral analogy is often difficult to imagine since investors in this case do not have complete market securities and information to track or hedge the cash flows. Indeed, such projects in today's world are relatively rare. In principle, cash flows from infrastructure projects could still be reasonably tracked by traded proxies in the market, albeit with some difficulty and error, despite the specificity of projects and the infrequency of real asset trading. Further, the risk-neutral technique cannot be worse, or more subjective, than estimating the appropriate risk-adjusted discount rate. Our previous discussion about discount rate selection vividly illustrates this point.

Illustrative case study

The valuation techniques and issues just presented are illustrated using data and information about the Dulles Greenway project in northern Virginia in the USA. This section: (a) provides an overview of the project, (b) presents a cash flow model that closely resembles the one created by the project's development consortium and (c) evaluates the project's economic viability by both traditional and option valuation techniques using this cash flow model.

Project background

The Dulles Greenway was among the first highway projects in the USA to be delivered by BOT franchise since the 19th-century, when the US commonly relied upon the private sector for infrastructure development. The Greenway is an extension of the existing Dulles Toll Road from Dulles International Airport into primarily undeveloped reaches around Leesburg, VA. The extension provides a more attractive commuter route than existing state roads from northern Virginia into the Washington, DC metropolitan area, and it is regarded, in part, as a catalyst of property development in outlying areas.

The Virginia Department of Transportation began planning the extension in 1987. In the following year, in the face of a $7 billion transportation needs deficit, the Virginia General Assembly passed legislation authorizing the private development of toll roads. Thereafter, a private consortium secured the right to develop the extension as a toll road from the state. As a completely private venture, the extension (dubbed the Dulles Greenway by the development consortium) would provide some forty years of cash flows to its investors and debt holders, without public subsidies. Revenues would depend almost exclusively upon toll receipts.

Initial projections by the consortium forecast approximately 20 000 vehicles per day for the first year of operation at a fixed toll rate of $1.50 with traffic increasing to 34 000 vehicles per day by 1995 at the same toll rate. Estimates of total capital costs were approximately $279 million. Equity investors contributed approximately $40 million while long-term fixed rate notes provided the balance of the financing. The project was originally scheduled to start construction in 1989 and operations in 1992, but difficulties in securing financing and environmental permits caused delay. During the four-year schedule slip, the consortium revisited their financial model and subsequently adjusted it by increasing traffic projections for the first year of operation to the daily ridership forecast of 34 000 expected by 1995 in the original estimate – thus neglecting the time actually required to build up traffic demand (Pae, 1995). In addition, the plan was to start with a toll rate of $1.75 and to raise this rate to $2.00 shortly thereafter. Construction finally commenced in September 1993, proceeded flawlessly and ended six months ahead of schedule in September 1995.

Within six months of opening, the project was in financial distress. Average daily traffic demand was an abysmally low 10 500. The toll rate was not raised to $2.00, but was reduced to $1.00 in March 1996. Future toll hikes were deferred in an attempt to increase ridership. By July 1996, road usage increased to 21 000 daily travellers, averaging 1–2% monthly growth. However, the net effect on projected revenues was marginal, as decreased toll rates offset the increase in ridership. The project's sponsors began discussions with the project's creditors in the summer of 1996 to work out a plan for deferring debt payments and restructuring loan contracts (Bailey, 1996).

Cash flow model

The investment analysis of the Dulles Greenway is reconstructed from an *ex ante* perspective using cash flow estimates and construction costs from financial models submitted by the consortium to the state. The assumptions and estimates described below roughly match those of the consortium's financial model (Toll Road Corporation of Virginia, 1993). To simplify the analysis, pre-construction, construction and other development costs of $279 million are split evenly over the two-year construction period, and financing, taxes, depreciation and other costs are ignored. The cash flows analysed are earnings before interest and taxes (EBIT), which occur annually over a 40-year operational period (see Figure 1), minus capital expenditures that occur in certain years during the period:

$$\text{CF} = \text{Gross Revenue} - \text{Operating Expenses} - \text{Capital Improvements} \tag{9}$$

$$\text{Gross Revenue} = \text{Average Daily Traffic} * \text{Average Toll Rate} * 365 \text{ days} \tag{10}$$

Average daily traffic demand is assumed to grow at a rate of 14% annually for the first six years of operation. Demand growth tapers off to a rate of 7% per year for the remaining 34 years. The schedule of average annual toll rates begins at $2.00 and gradually rises to $3.00 by the 15th year of operation; it is assumed that the consortium's traffic projections captured the relationship between traffic demand and toll rates. Operating expenses include operations and maintenance costs, various fees, police costs, lease payments and other expenses from the developer's model. Operating expenses start at $9 million per year and grow at a constant rate of 5% annually. Capital improvements include planned repaving and road widening activities.

Traditional valuation

With the basic structure of the cash flow model developed, a discount rate was determined using Eqs 3 and 4. Deriving the project's β_a depends upon judgment of appropriate values for $\beta_{revenue}$ and the PV(fixed cost)/

	Operating and capital projections							Valuation		
Period	Avg. daily traffic [1]	Toll per vehicle [2]	Gross revenue [3]	Operating expenses [4]	Capital improvements [5]	EBIT [6]	Capital expenditure [7]	Discount factor [8]	Discounted EBIT [9]	Discounted capital expenditure [10]
1							(139,500,000)	0.8651		(120,674,740)
2							(139,500,000)	0.7483		(104,389,914)
3	20,000	2.00	14,600,000	(9,000,000)		5,600,000		0.6473	3,625,054	
4	22,800	2.00	16,644,000	(9,450,000)		7,194,000		0.5600	4,028,460	
5	25,992	2.00	18,974,160	(9,922,500)		9,051,660		0.4844	4,384,692	
6	29,631	2.25	24,334,360	(10,418,625)		13,915,735		0.4190	5,831,216	
7	33,779	2.25	27,741,171	(10,939,556)		16,801,614		0.3625	6,090,405	
8	38,508	2.50	35,138,816	(11,486,534)		23,652,282		0.3136	7,416,694	
9	41,204	2.50	37,598,533	(12,060,861)		25,537,672		0.2713	6,927,249	
10	44,088	2.50	40,230,431	(12,663,904)	(3,000,000)	24,566,527		0.2347	5,764,550	
11	47,174	2.65	45,629,354	(13,297,099)		32,332,255		0.2030	6,562,961	
12	50,477	2.65	48,823,409	(13,961,954)	(1,700,000)	33,161,455		0.1756	5,822,903	
13	54,010	2.65	52,241,048	(14,660,052)		37,580,996		0.1519	5,708,427	
14	57,791	2.85	60,116,632	(15,393,054)		44,723,578		0.1314	5,876,610	
15	61,836	2.85	64,324,796	(16,162,707)		48,162,090		0.1137	5,474,416	
16	66,164	2.85	68,827,532	(16,970,842)	(9,400,000)	42,456,690		0.0983	4,174,657	
17	70,796	3.00	77,521,536	(17,819,384)		59,702,152		0.0851	5,078,165	
18	75,752	3.00	82,948,044	(18,710,354)		64,237,690		0.0736	4,726,601	
19	81,054	3.00	88,754,407	(19,645,871)		69,108,536		0.0637	4,398,786	
20	86,728	3.00	94,967,215	(20,628,165)	(10,400,000)	63,939,050		0.0551	3,520,542	
.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	
40	335,610	3.00	367,493,158	(54,732,662)		312,760,495		0.0030	948,197	
41	359,103	3.00	393,217,679	(57,469,296)		335,748,383		0.0026	880,527	
42	384,240	3.00	420,742,916	(60,342,760)		360,400,156		0.0023	817,628	
			PVs:	**203,379,185**		**(62, 180, 100)**	**(2,499,370)**	**=**	**138,699,715**	**(225, 064, 654)**

Valuation results:	**(86,364,940)**
Net present value	12.29%
Internal rate of return	

Figure 1 Dulles Greenway valuation model

PV(EBIT) ratio. This toll road is more strongly linked to general economic conditions than many similar projects since the initial traffic volume, in particular, is tied to outlying property development. General economic development is strongly influenced by market forces such as prevailing interest rates and consumer behavior, so downturns in the overall economy tend to sour property development. For this reason, $\beta_{revenue} = 1.0$ was chosen. Once the project stabilizes, the ratio of the project's fixed costs to EBIT should fall towards a low percentage, so a value of 0.2 was chosen. The risk-free rate, R_f, is normally determined from the yields on national debt, and in this case, a value of 6% was selected. Finally, the equity risk premium, $R_m - R_f$, is historically 6–8% in the USA, so a conservative value of 8% was chosen. Substituting appropriate values into Eq. 3 and then Eq. 4 results in a discount rate of 15.6%.

This value is consistent with the project's general risk characteristics. The project was one of the first private toll road ventures in the USA in the 20th century, and its traffic volume depended largely upon the pace of development activities in a primarily rural area of northern Virginia. These attributes coupled with the lack of any arrangements to preclude the improvement of competing free routes by the Virginia Department of Transportation support the selection of a higher discount rate for the calculation of the project's value.

A base case analysis follows the consortium's original expectation of an average of 20 000 vehicles per day in the first year of operation; all other parameters are set as described previously. Under these conditions, the project's NPV is negative \$86.3 million as illustrated in Figure 1, so the investment appears rather suspect. One-way sensitivity analyses are illustrated in the tornado diagram in Figure 2. The parameters shown were varied as follows: (a) initial average daily traffic from 10 000 to 35 000 vehicles per day, (b) discount rate from 10% to 20%, (c) capital costs from a 10% decrease to a 40% increase and (d) initial traffic growth during the first six years from 2% to 17% annually. As

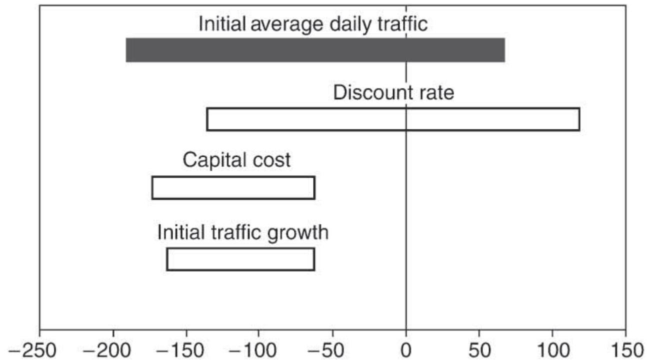

Figure 2 Base case: one-way sensitivity of NPV ($millions)

Table 1 Sensitivity of NPV ($millions) to R_a and avg. daily traffic

Discount rate			Initial average daily traffic				
$\beta_{revenue}$	PV(fixed) PV(EBIT)	R_a (%)	14 000	20 000	26 000	34 000	40 000
0.6	0.1	11.3	(73.4)	43.7	160.9	317.1	434.3
0.6	0.2	11.8	(86.4)	21.6	129.6	273.6	381.6
0.6	0.3	12.2	(97.8)	2.0	101.8	234.8	334.6
0.6	0.4	12.7	(107.9)	(15.4)	77.0	200.3	292.7
0.8	0.1	13.0	(113.9)	(25.9)	62.0	179.3	267.2
0.8	0.2	13.7	(124.5)	(44.7)	35.2	141.6	221.4
0.8	0.3	14.3	(133.4)	(60.7)	12.0	109.0	181.7
0.8	0.4	15.0	(141.0)	(74.5)	(8.0)	80.7	147.2
1.0	0.1	14.8	(139.2)	(71.2)	(3.2)	87.4	155.4
1.0	0.2	15.6	(147.4)	(86.4)	(25.4)	56.0	117.0
1.0	0.3	16.4	(154.0)	(99.0)	(43.9)	29.5	84.5
1.0	0.4	17.2	(159.3)	(109.4)	(59.6)	6.9	56.8
1.2	0.1	16.6	(155.1)	(101.2)	(47.3)	24.6	78.6
1.2	0.2	17.5	(161.1)	(113.1)	(65.1)	(1.1)	46.9
1.2	0.3	18.5	(165.8)	(122.8)	(79.8)	(22.5)	20.5
1.2	0.4	19.4	(169.3)	(130.6)	(91.9)	(40.3)	(1.6)

the figure illustrates, the project is quite sensitive to the discount rate and the initial average daily traffic volume. Moreover, it is only attractive at higher traffic volumes and lower discount rates. If traffic volume falls below roughly 28 500 vehicles per day, the project's NPV dips below zero. Similarly, if the discount rate is higher than 12.3%, NPV becomes negative.

Two-way sensitivity analysis of the project's NPV to simultaneous changes in initial traffic volume and discount rate is shown in Table 1. Note that the table also depicts the values for the parameters ($\beta_{revenue}$ and PV[fixed cost]/PV[EBIT]) used to derive the corresponding discount rate. This table clearly indicates that the project is somewhat precarious. Miscalculation of the expected traffic and the appropriate discount rate can quickly change the project's outlook. As mentioned, the start of construction slipped from 1989 to 1993, and during this period, the project's developers changed their expectation of average daily traffic in the first year to 34 000 vehicles per day. In this adjusted case, with all other parameters equal to their base case values, the project's NPV is positive $56 million. Obviously, the project's investors felt confident enough in this forecast to proceed.

Deferment option

Traditional valuation suggests that the project is not exceedingly robust, and this leaves a decision-maker in a quandary. The investment decision hinges upon the strength of the traffic forecasts and the confidence in the judgment about the linkage between the project and general economic conditions. The project's developers, however, have another potential alternative; they could

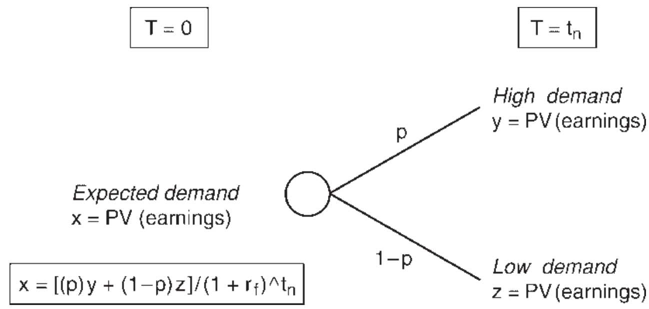

Figure 3 Binomial model for establishing risk neutral probabilities

defer the project. Deferment could allow the acquisition of better information and the observation of economic growth in the outlying regions.

A simple binomial model is presented to value the option of deferring an infrastructure investment. This model is a discrete-time, economically corrected decision tree, and it more explicitly recognizes the uncertainty of initial demand for an infrastructure asset and its effect on the value of a project. Additionally, this model provides a rough estimate of the value of acquiring more information to help resolve initial demand uncertainty.

The following general assumptions are made to simplify the model:

(1) Project value is represented by the present value of earnings before interest and taxes (EBIT) over the concession period; the present value of initial capital costs is taken as the exercise price of the option.
(2) The option to wait to build the asset is limited. Furthermore, the length of the concession remains the same regardless of when development begins.
(3) Initial demand is the critical variable. Demand growth thereafter increases in a relatively consistent and predictable manner.
(4) Waiting to invest has no direct cost. That is, the present value of net earnings and costs in t_n will be similar to their current values. Inflation, therefore, is ignored for simplicity.
(5) Initial demand uncertainty can be resolved (or at least narrowed) by observing key variables and conditions associated with the project at time t_n.

Most assumptions stated above can be easily relaxed without jeopardizing the fundamental evaluation methodology. For example, adjustments can always be made to the basic cash flow model to reflect changes in the growth rate or to include direct costs of waiting.

Figure 3 illustrates the model's basic set-up in a risk-neutral world. First, an analyst must identify three states of future demand, in this case the average daily traffic volume during the toll road's first year of operation. Expected, high and low demands were assigned values of 20 000, 34 000 and 10 000 vehicles per day respectively. Of course, these assignments benefit from hindsight, and these figures are in fact associated with different events in the case history. Nonetheless, the original estimate for initial traffic demand (20 000) seems an appropriate expected value, while 34 000 and 10 000 appear to be realistic optimistic and pessimistic estimates. Before applying the model, an analyst must also: (a) build a cash flow model, similar to the one shown in Figure 1 to estimate the present value of earnings and capital costs determined using a risk-adjusted discount rate and (b) establish the period when the option to defer expires, t_n; here, we assume that $t_n = 5$ years. Other valuation parameters in the cash flow model are similar to those adopted in the base case analysis discussed previously.

The model in Figure 3 is used to establish the risk-neutral probabilities for future states of demand. Using the inputs just described, the present value of earnings at $t = 0$ for the expected demand and present values of earnings at t_n for high and low demands are estimated as \$138.7 million, \$281.1 million and \$37.0 million respectively. Risk-neutral probabilities, p and $1 - p$, are then calculated according to the 'boxed' formula in Figure 3. In this case, the risk-neutral probabilities were calculated as 0.61 for the high initial traffic volume and 0.39 for the low initial traffic volume.

These risk-neutral probabilities can now be used to evaluate the value of the project embedded with the deferral option as illustrated in Figure 4. If one assumes that the demand uncertainty will unravel by the time t_n approaches, one may choose to defer the project until that period. In that case, the project value can never be less than zero since it can always be abandoned if the capital costs are greater than the present value of earnings in future states. The value of the deferment

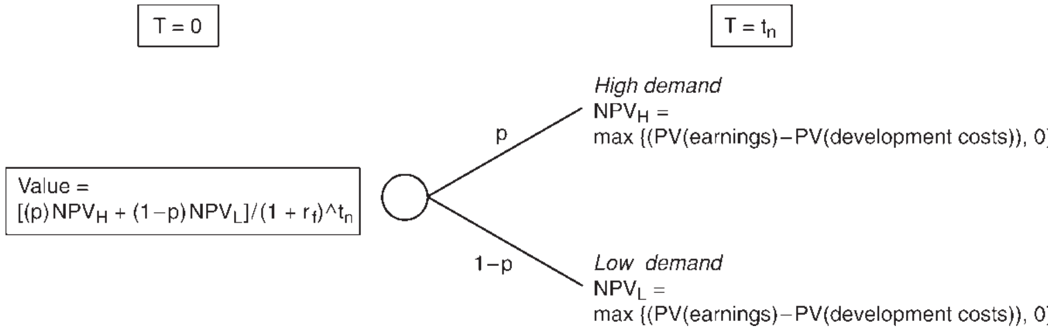

Figure 4 Project value with embedded deferral option

option itself is simply the value calculated in the 'boxed' formula in Figure 4 minus the base case project value.

In this case, NPV_H = \$56.0 million since at a volume of 34 000 vehicles the project is attractive and development proceeds while $NPV_L = 0$ since at a volume of 10 000 vehicles the project is unattractive and development does not commence. After substituting appropriate quantities into the 'boxed' equation in Figure 4, the value of the project with the embedded deferral option is \$25.5 million while the value of the deferment option itself is \$111.8 million (\$25.5M – (–\$86.3M)). This compares quite favourably with the base case NPV of negative \$86.3 million.

Discussion of case study results

The case study highlights a number of valuation issues discussed earlier. Foremost, traditional valuation indicates that the project is far from robust, but the option model suggests that deferment has significant value. The choice of investing now or later requires the decision-maker to weigh the assumptions made against this modelling outcome, and this choice depends primarily upon traffic demand. The option model assumes that time will tell, and a clearer picture of demand will develop within five years. Hence, the ultimate decision is likely to depend upon whether additional time will improve initial traffic volume predictions.

More fundamentally, Eq. 3 and 4 provide an analyst a logical basis for estimating a discount rate, and then testing the sensitivity of the project's evaluation to changes in the parameters used to derive the discount rate rather than direct changes to the discount rate. In this case, judgment regarding the interdependency between the project and general economic conditions is rather important since lower $\beta_{revenue}$ values result in lower discount rates; still, this project's conditions imply that a higher value is warranted. Further, the option model presented is not mathematically complex. The skills required for its use are no different than those necessary in traditional valuation. Therefore, with modest effort, analysts can quickly gauge the approximate value of deferring a project. This value increases as the uncertainty of the underlying variable (in this case the traffic volume prediction) increases. The option valuation depicted uses a one-step binomial tree, so the uncertainty is captured by the 'magnitude of swing' of the initial traffic volume. Another possible alternative is to model the change in average daily traffic (column 1 of Figure 1) by some form of Eq. 7, be it a lognormal, a mean-reverting or a Poisson process with jumps. As discussed previously, this change imposes stronger assumptions and increases mathematical complexity. Given the numerous assumptions already incorporated into the cash flow model, this added complexity introduces new modelling 'costs' and may not provide any better representation of the true picture.

Interestingly, the binomial approach demonstrated also effectively separates the modelling procedure into two parts. First, transportation economists are free to develop their traffic projections by adjusting parameters and assumptions such as demand elasticity and growth. Then, project analysts can take over and evaluate the project and its options as depicted. This creates flexibility in the evaluation procedure. If one were to adopt a continuous-time model instead, these two parts would overlap, and, as just discussed, whether the additional coordination required would be justified is unclear.

Finally, the case also depicts important aspects regarding the relationship between government and private developers. The circumstances are reminiscent of the proverbial 'chicken or egg' problem. Outlying property development may not materialize without the more efficient commuter route, but project financing of the route could very well depend upon the rate of outlying growth. Had the government conducted its own assessment of the project's economic viability prior to granting the concession, this dilemma may have become apparent and an alternative strategy for developing the route pursued. Perhaps, the state could have improved the project's current outlook by guaranteeing a minimum amount of annual toll revenue during the project's early stages or by securing the project's debt instruments. Regardless, an evaluation by the government would have improved its understanding of the issues involved when opting for a private project financing. Some might suggest that the distress that resulted is not a real concern of the government; the state obtained a highway extension that it wanted at virtually no economic cost to itself. This perspective, however, does not consider the importance of concession conditions and success upon the long-term outlook of BOT arrangements. The BOT market is unlikely to fully mature without cases of mutual benefit between the public and private sectors.

Conclusion

Facilities delivered through project financing arrangements supported from private capital sources can assist public infrastructure owners in their search for strategies to meet society's needs amidst funding constraints. Public owners, however, should properly evaluate the economic viability of such arrangements prior to soliciting private proposals to fully appreciate the issues. The techniques presented illustrate the factors involved in selecting an appropriate discount rate for valuing projects traditionally and deploying a binomial model for valuing the option to defer. The writers characterize this option model as an 'economically corrected' decision-tree. Its appeal lies in its simplicity and its applicability. The assumptions governing its use are generally reasonable, and its analytical methods are quite accessible to practitioners. These techniques can aid in the analysis of a project's private finance potential and investment timing. Discussion throughout this paper, however, highlights the significance of informed judgment. Decision-makers should properly appraise project variables and carefully consider the assumptions underlying valuation methods, particularly real option models. Inappropriate applications can misinform and result in improper choices.

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