A Fair Value Approach to Valuing Public Infrastructure Projects and the Risk Transfer in Public Private Partnerships

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1. Introduction

It is widely predicted that governments worldwide will invest tens of trillions of dollars in new infrastructure investments over the next decade. Which of the many candidate projects should be undertaken? Is entering a public private partnership (P3) cost effective? How do alternative revenue and risk-sharing contracts affect government cost? What funding mechanisms should be used? The ability to accurately value projects and related contracts is vital for governments to give informed answers to such questions, and to fulfill their responsibilities as stewards of public resources. Yet analyses of public infrastructure investments often rely on government accounting conventions and valuation approaches that significantly misrepresent the financial costs and benefits of both the projects and the associated contractual arrangements.

As a step toward providing public managers with practical tools designed to more closely align infrastructure valuation practices with financial principles, and to suggest the magnitude of the distortions arising from analyses that neglect the cost of risk, in this paper we: (1) briefly recap the theoretical and practical considerations surrounding the use of a fair value approach to assessing public investment projects; (2) develop a framework consistent with that approach and with private sector practice for valuing public investment projects and the various claims associated with them, with an emphasis on P3s; and (3) illustrate the implications of that approach versus popularly used alternatives for a hypothetical toll road project. While our main emphasis is on how valuation practices can be improved, we also discuss several related issues including: whether and when arrangements such as P3s and infrastructure banks might legitimately alleviate government funding constraints; the implications of the availability of tax exempt municipal bond funding in the U.S.; and the incentives created by budgetary rules for U.S. state and local governments. Engel et. al. (2020) provides a useful and complementary analysis of the effects of P3s on efficiency, incentives, and governance.

The fair value approach posits that the cost of capital for any real or financial investment reflects the market price of the associated risks, or the best available approximation thereof. Hence the cost of capital for a given project is essentially the same for governments and private investors. The government's borrowing rate, although frequently used by governments for discounting project cash flows, is not a full measure of its cost of capital for a risky investment. That conclusion rests on the observation that a risky investment can never be fully financed by low-risk government debt. Taxpayers and other government stakeholders are the residual claimants to any profits or losses; effectively citizens are conscripted equity holders in all risky investments undertaken by governments.

The fair value approach is largely good news for P3s, as it suggests that a common concern about them—that they entail a higher cost of capital because private contractors have to "make a profit"—is misplaced. In fact there is no necessary tradeoff between the potentially greater operational efficiencies of P3s and higher capital costs as long as the contracting process is sufficiently competitive to ensure that private partners earn a return that is commensurate with the risk they assume. However, because a fair value approach generally assigns a cost of capital that is higher than a government's borrowing rate, it tends to reduce the universe of projects which appear to be worthwhile investments. The exception is that projects that have countercyclical benefits will appear more valuable than under typical discounting practices (Gollier and Cherbonnier, 2018). A fair value approach also tends to increase the assessed cost of contracts that shift risk from private partners to the government, which will make some P3s arrangements appear significantly less attractive than under current valuation practices.

Reliance on fair value principles suggests that a textbook approach to valuation—projecting associated net cash flows and assessing their risk, and then discounting by the corresponding cost of capital—applies to public infrastructure investments. While true, valuing public infrastructure investments entails complications that are usually absent from standard capital budgeting exercises that private firms would undertake. A contribution of the analysis here is to show how those nonstandard features can be incorporated into the valuation process on a consistent and comprehensive basis that avoids double counting, and that clarifies the incidence of costs and benefits under alternative contractual arrangements.

To value public infrastructure investments, non-standard considerations include how to incorporate public benefit flows that are in excess of revenue flows, and the cost of any negative externalities including tax distortions. It is also critical to assess the value of various types of subsidies and their incidence. Inferring the cost of capital can be tricky because of the limited availability of data on historical costs and revenues for most types of infrastructure projects, and the less obvious choices for private sector firms with comparable risk exposures.

Subsidies to infrastructure investments take many forms. Those include: direct government payments; in-kind services; tax breaks to private partners; credit subsidies via preferentially priced direct government loans or credit guarantees; access to tax-advantaged municipal bond financing; minimum revenue guarantees in P3s; and implicit guarantees such as those arising from the renegotiation of contracts when revenues fail to meet expectations. A number of these subsidies are contingent claims that can be valued most accurately using derivatives pricing methods, and a major contribution of the analysis is to show how some of these common contractual features can be valued using those methods.

A further consideration is that multiple levels of government may provide subsidies (e.g., muni bonds provide federal resources to state, local and private entities). While it is natural that a local government, like a private firm, would treat federal subsidies as unambiguously increasing the attractiveness of undertaking a project, an analysis of social value requires taking into account the comprehensive cost of subsidies at all levels of government.

The analysis here is related to several distinct strands of literature. It builds most directly on Lucas (2012 & 2014a) and references therein, which discuss the reasons for the systematic understatement by governments of the cost of their financial activities, and develop and calibrate models to evaluate government financial costs more comprehensively for a variety of applications. More fundamentally, our analysis relies on the conceptual foundations of modern financial valuation and derivatives pricing techniques (among others, Arrow and Debreu (1954), Modigliani and Miller (1958), Sharpe (1964), Black and Scholes (1973), Merton (1973) and Black(1976)). Our analysis also expands on themes developed in more recent analyses of infrastructure investments and P3s, particularly Engel et. al. (2014 and 2020) and references therein. Finally, our analysis is related to fundamental issues in public finance and public choice. However, those traditions typically place more emphasis than we do on distributional consequences and tax distortions, but they abstract from our main focus which is the effects of risk on value.

The remainder of the paper is organized as follows: Section 2 briefly recaps the theoretical and practical considerations associated with governments taking a fair value approach to valuation. Section 3 lays out a valuation framework for infrastructure projects and for the various contracts associated with them, including those that commonly arise in P3s. Section 4 applies those ideas to compare the construction and operation of a hypothetical toll road via and P3 and via a more traditional financing structure, and to illustrate the magnitude of the effects of alternative assumptions about capital costs. Section 5 discusses funding-related issues. Section 6 concludes.

2. Government cost of capital

The basic presumption that value of government investments should be evaluated using market prices rests on the logic that (a) the risk incurred is ultimately borne by taxpayers and other government stakeholders (henceforth referred to as citizens), and (b) market prices are the best available measure of opportunity cost for most investments.[3] When a government assumes the risk of investing in an infrastructure project, any losses that are incurred eventually must be covered by increases in future taxes, or cuts to other spending. Similarly, any profits can be used to reduce future taxes or to fund other government spending. Effectively then, citizens are equity holders in public infrastructure investments.

In a highly influential analysis, Arrow and Lind (1970) suggested that governments have a lower cost of capital than the private sector because they can spread project risk more widely, and by doing so effectively eliminate it. However, as was recognized by many leading economists of the time, that line of reasoning does not apply to aggregate or undiversifiable risks. Furthermore, modern capital markets spread investment risk widely across investors, perhaps more broadly than governments typically do.[4] The evidence from the asset pricing literature suggests that diversifiable risk does not carry a risk premium. Hence, the undiversifiable risk associated with infrastructure investment represents a cost that is independent of whether the sponsor is a government or a private entity, and market risk premiums are a reflection of that cost. (See Lucas, 2014b, for a more complete discussion of these and related issues.)

Some might argue that the government can fund a project by issuing public debt that carries a low interest rate. However, issuing public debt can only alter the timing of when project cash flows are passed through to its citizens. Adjustments in the size of the public debt do not in themselves affect the financial position of the government, rather they are a means of financing.

[3] For projects with very long-lived effects such as those to mitigate climate change, reference market prices may be unavailable and other approaches to identifying value are necessary. The focus here is on valuation of the vast majority of infrastructure investments that have at least loose analogues in private sector investments.

[4] The degree to which the government is able to efficiently distribute risk relative to the private sector is ultimately an empirical question. For the state and local governments that undertake a large share of infrastructure investments, their tax base is likely to be narrow relative to the base of international investors that participate in global capital markets.

That is, if the government covers a negative cash flow by issuing additional debt, that debt eventually must be repaid with interest. Issuing the debt is value neutral because the amount borrowed equals the present value of future repayments. The interest rate on the debt depends on the strength of the government's promise to repay it, and other features like whether it is tax-advantaged, but not on the risk of any particular project. Despite that logic, governments often identify their cost of capital with their own borrowing rate.

For revenue bonds whose payments are backed only by project cash flows, the riskiness of the debt and therefore the interest rate investors demand depend on project risk and the amount of debt issued. The obligation to pay debt holders from project cash flows adds leverage to the position of citizens in their role as equity holders or residual claimants. The more debt that is added to the capital structure, the riskier is the equity. Whatever the mix of debt and equity used for funding, the total risk is conserved, and depends on the characteristics of the project; the famous Modigliani Miller theorem holds for both government and private sector investments.[5]

The recognition that the value of a public infrastructure project depends on the market price of the associated risks, and that identifying the cost of risk can require approximations, suggests taking a fair value approach to evaluating project value. This approach measures the value of cash flows at market prices when possible, but allows approximations when directly comparable market prices are unavailable or unreliable due to market conditions. A fair-value approach generally entails applying the discount rates on expected future cash flows that private financial institutions would apply.

Along with aligning government valuations with economic principles, a fair value approach has the advantage of harmonizing the perspectives of the government and potential private partners. Understanding the value proposition for a private partner can improve outcomes, for instance, by helping governments avoid accepting unrealistically low bids that are likely to be renegotiated.

3. Valuation framework

The framework presented here takes an adjusted present value (APV) approach, which calls for first calculating the standalone value of a project as if it were entirely equity financed, and then separately adjusting for financing side effects such as the value of municipal bond tax exemptions or subsidized government guarantees (see, e.g., Brealey et. al., 2019).

In this section we discuss the elements of an APV analysis as they pertain to infrastructure projects, starting with the basics of how to identify the relevant standalone cash flows and project discount rates. We also discuss how some of the most common financing side effects and subsidy arrangements can be valued using risk-adjusted discount rates and derivatives pricing techniques.

A popular alternative to APV is the weighted average cost of capital (WACC) approach, which adjusts the discount rate so as to implicitly take into account the value of financing side effects. In theory both approaches should yield identical results when correctly applied, and in practice

[5] As for private sector investments, this abstracts from tax effects and the potential costs of financial distress when leverage is high.

the results tend to be similar for many private sector applications. However, APV is the only workable approach in this context because of the complexity of subsidies and contractual arrangements, and the need to understand how the value of various claims affect different project participants.

We take a textbook approach to valuation rather than a adopting more complicated academic model for several reasons. The workhorse APV model, implemented using the CAPM to identify discount rates, is relatively easy to understand and implement. Because it is widely used by firms in the private sector to evaluate investment opportunities, expertise and standard practices are available to help discipline the process, which promotes credibility and transparency. Furthermore, alternative models that have been proposed to estimate discount rates have so far not yielded sufficiently robust outcomes to be widely adopted in practice.[6]

3.1 Cash flows

The first step in any NPV analysis of project value is to estimate expected cash inflows and outflows over the life of the project. For long-lived projects, cash flows often are explicitly forecast through some terminal date, at which time a liquidating cash flow represents the net present value of any residual cash flows past that period. Cash inflows are composed of revenues from user fees, rents and other charges. Cash outflows include capital expenditures, maintenance, salaries and other expenses.[7]

An important consideration for public infrastructure investments is how to incorporate the value created for society beyond that which is reflected in revenues. Significant differences between revenues and social benefits may arise for many reasons. For instance, a toll road may generate significant time savings for drivers on nearby highways by reducing congestion. Another example is that to increase access and encourage use, governments may choose to set user charges below cost and below the public's willingness to pay. Negative externalities, such as increased CO_2 emissions from a public power plant, or the costs arising from the associated distortionary taxes needed to help pay for the project, also need to be incorporated.

In the APV framework presented here, the value of any such positive or negative externalities would be quantified and incorporated as a positive or negative cash flow. There are two possibilities for how to include them: (a) along with the cash flows for the standalone project; and (b) separately as an input into the adjustments to the base case value. The first option makes sense when the externalities are thought to be roughly proportional to the service flows net of cost from the project, and when the perspective of interest is that of the government. As line items to be incorporated into the cash flows of the standalone analysis, they might be described as "imputed additional revenues" and "imputed additional costs." The second option is preferred when the risk of the externalities is significantly different than of the service flows net of cost, or

[6] Ammar et. al. (2013) estimate a Fama-French style model to explain returns to infrastructure, and find that returns covary positively with the market and also depend on the other Fama-French factors.
[7] Depreciation is a non-cash expense. Its cost is indirectly reflected in capital expenditure and maintenance costs.

when the project is being evaluated from the perspective of an entity like a private partner that does not care about their value.

Although imputing the value of externalities requires judgment and involves considerable uncertainty, attempting to do so is unavoidable when the objective is to undertake a full and formal cost-benefit analysis of a project. The public finance literature provides some guidance on imputing the social value-added for public goods, but there is no general agreement on critical issues such as how to choose a social welfare function to use as an aggregator across different beneficiaries. Fortunately, for valuation objectives such as determining budgetary costs or for negotiating contracts with private partners, quantifying the value of externalities is often less critical.

Cash and in-kind subsidies also affect the cash flows associated with an infrastructure project. However, as for financing side effects, the present value of these subsidies can be evaluated separately from the calculations for the standalone project, and then incorporated into the final APV calculation. One reason for treating all types of subsidies separately is that their effect on net value will depend on whose perspective is being considered. Another reason is that the risk characteristics of subsidies, and hence the appropriate rate to discount them, is often quite different than for the project as a whole.

Several examples illustrate the complications associated with cash and in-kind subsidies. Imagine that a government agrees to perform certain maintenance functions for its private partner for free or at below its cost (e.g., dredging a port). From the perspective of the government, the subsidy element of that service provision is an additional operating cost associated with the project; it adds to the present value of costs. From the perspective of the private partner, there is no need to track the annual cost savings. Rather, the benefit received will be implicit in its lower projected operating costs. Similarly, the free provision of land to a private partner should be treated as a capital expenditure for the government equal in value to what the land could be sold for to a private buyer, taking into account any use restrictions and other features that would affect its market value. For the private partner, the benefit from the free land use is implicit in reduced capital expenditures.

Another example is a contract obligating a government to make a constant annual payment to a private partner for some number of years to help defray fixed operating expenses. Clearly the contract in itself is positive NPV for the private partner and negative NPV by the same amount for the government. A further reason to value this contract separately is that the risk of the fixed contractual payments, and hence the appropriate discount rate, is likely to be considerably lower than for the project as a whole. Relatedly, we will see that a minimum revenue guarantee from the government, which also might be viewed in terms of its expected cash flows, actually is a package of put options whose value depends on the volatility of revenues. Because of that optionality, the associated cost of risk is higher than for the underlying project as a whole. That makes the guarantee more valuable to a private partner, and more costly to the government, than it would appear to be if the expected cash flows from the guarantee were rolled directly into the project valuation.

3.2 Cost of capital

The approaches suggested here to identify the cost of capital (i.e., the discount rate) for valuing infrastructure projects and associated claims follows the logic of modern finance theory, as taught in business schools and widely adopted by large corporations and investment professionals. For completeness we provide a basic description of some of these well-documented procedures. However, our main focus will be on considerations that are more specific to public infrastructure projects. Those include the greater difficulty of identifying private sector firms with comparable risk exposures; the limited availability of data on historical costs and revenues; and the pervasive use of financial and non-financial subsidies and guarantees that affect risk and hence capital costs. We emphasize that the relevant cost of capital will be different for the project as a standalone entity and for different claims related to the project, and give examples where such distinctions typically need to be made.

3.2.1 The Capital Asset Pricing Model

The cost of capital for a project or financial contract reflects the pure time value of money plus the priced risk of the associated cash flows. The workhorse model for identifying a project's cost of capital is the Capital Asset Pricing Model (CAPM). It posits that investments whose risk can be inexpensively avoided through portfolio diversification will only earn the risk-free rate. However, investments exposed to "undiversifiable" or "market" risk on average earn a market risk premium in addition to the risk-free rate. Equivalently, expected cash flows from the projects with more market risk exposure, as measured are discounted at higher rates.[8]

The CAPM quantifies undiversifiable risk for a standalone, all-equity financed project through the idea of an "asset beta." Asset betas are estimated using historical data on stock returns on firms with similar risk exposures to the project under consideration. Specifically, stock returns on individual stocks or industry portfolios are regressed on the return to a broad market index like the S&P500 to identify an equity beta. The equity betas are unlevered to remove the effects of debt financing on the risk of equity, yielding an "unlevered" or asset beta.[9]

The CAPM provides a discount rate for project's cash flows through the equation:

$$E(r_A) = r_f + \beta_A(E(r_m) - r_f) \tag{1}$$

[8] The intellectual appeal of the CAPM is that a similar story can be told in terms of utility functions and state prices, with higher values today for future payoffs that occur in high marginal utility states of the world. The CAPM equation can be derived from a general equilibrium pricing model under the assumption of quadratic utility and consumption that is equal to asset payoffs. Drawbacks include that it its predictive capabilities for asset returns are limited, and that it abstracts from other factors likely to affect the cost of capital like liquidity and size. Despite those drawbacks, it is widely used because of its simplicity and because competing models are also poor at forecasting returns.

[9] An adjustment can also be made for cash holdings, which are like negative debt. That adjustment tends to be small for most industries. Whether the adjustment for cash should be included depends on the cash needs of the project. If the project entails cash holdings at similar ratios to those of the comparison firms, no adjustment for cash is necessary.

$E(r_A)$ is the expected return on assets with similar market risk to the project, and hence is appropriate discount rate to apply to its expected cash flows; r_f is the risk-free rate; and $E(r_m)$ is the expected return on the market. β_A is the asset beta. Note that the APV approach taken here requires discounting project cash flows as if the project is all equity financed, and that asset betas are designed to do just that. The risk-free rate is generally taken to be the prevailing short-term (e.g., 3 month) Treasury rate, and a typical estimate of the market risk premium, i.e., $\left(E(r_m) - r_f\right)$, would be in the range of 5 to 7 percent.

3.2.2 Estimation approaches

A relatively simple and transparent way to assign a cost of capital to a public infrastructure project is by associating an asset beta with it and using equation (1) to derive a discount rate to apply to the project cash flows. Estimates of asset betas by industry are readily available, for instance from the popular website of Professor Aswath Damodaran at NYU.[10] Table 1 shows cash-adjusted asset betas for selected industries from that source..

The most relevant comparison industry will depend on the project. For example, for a toll road, the industries in Table 1 whose cash flows are likely to have a similar aggregate risk exposure include “trucking” (cash-adjusted asset beta of .71) and “transportation” (cash-adjusted asset beta of .9). One possibility would be to use the asset beta for trucking on the grounds that the transportation category is too broad and presumably includes firms like passenger airlines for which demand is more cyclical than highway usage. Or if trucking were viewed as too specific, another possibility would be to use an average of the two. The difference for the discount rate between those two choices is only about half a percentage point, assuming a 6% equity premium.

As another example, for a water treatment plant the natural choice from the Table 1 industry list is “utility (water),” (cash-adjusted asset beta of .32). The much lower market risk for water than for toll roads, and correspondingly lower implied discount rate, reflects the fairly stable demand for water over the business cycle, and perhaps the stabilizing effects of rate of return regulations on utility revenues.

For other public facility investments like ports or airports, it is less clear how one would impute an asset beta from the list of industries in Table 1. A possibility would be to use a broad industrial average of asset betas. Another would be to handpick a list of comparison firms (e.g., shipping companies for ports) and calculate asset betas from data on their historical returns.

Another possibility would be to try to infer asset betas from historical time series data on the returns to infrastructure funds. However, because infrastructure investments are generally privately held and trade infrequently, reliable information on returns is not available. Andonov et. al. (2018) analyze proprietary data from Preqin, a leading provider of data on alternative asset classes, and find that that the stream of cash flows delivered by private infrastructure funds to

[10] http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html

most institutional investors is very similar to that delivered by other types of private equity.[11] That suggests returns on private equity as another reference point for inferring asset betas.

There are several other options for estimating betas as inputs into constructing project discount rates. One is to collect cash flow data from similar projects and regress that data on overall market returns. A practical limitation is that for public infrastructure projects, time series data on cash flows is generally not publicly available, although some governments may have relevant information from past projects. Data may be available on revenues but not on costs.[12] A conceptual limitation to inferring betas from revenue data is that it doesn't include any imputed additional revenues, and it may include the effects of certain types of subsidy payments. Furthermore, estimates of asset betas based only on revenues are downward biased when fixed costs create operating leverage.[13]

Another possibility is to regress other variables likely to be associated with value on market returns. Again taking the example of toll roads, regressing detrended annual passenger miles driven on annual market returns gives an indication of the correlation between the value of road services and the overall market. Historical revenue data on toll roads, and data on passenger miles driven, are available from the U.S. Department of Transportation. In Section 4 we show how asset betas based on that data compare with those inferred from the stock return-based procedure using Damodaran's asset betas for related industries.

3.2.3 Additional considerations

A fundamental question is whether the procedure of deriving asset betas from equity betas should be expected to reasonably capture the cost of market risk for public infrastructure projects. Our view is that for the evaluation of standalone, all-equity financed projects, the answer is often "yes." The procedure implicitly assumes that the earnings of the comparison firms have a similar exposure to market risk as the earnings--properly measured to include any "imputed additional revenues" discussed in section 3.1--of the infrastructure project. However, the cash flows associated with associated transactions, whose dynamics may differ significantly from the overall project, must be discounted at a cost of capital consistent with their risk, as illustrated in the example below.

It is important to understand that assigning a cost of capital to a new project or associated claim is challenging even for the most sophisticated corporations and investors, and it always involves simplifications and approximations. A realistic goal is to identify discount rates that have no discernable bias, even when there is considerable uncertainty around any point estimate ultimately selected. And while identifying a point estimate may be necessary for purposes like budgetary accounting, sensitivity analysis that includes a plausible range of discount rates is useful for understanding and communicating the uncertainty related to the cost of capital.

[11] The exception is U.S. public pension plans, that receive lower returns on infrastructure than other institutional investors.
[12] See a description of various P3 databases worldwide in Prats, J., Demaestri, E., Chiara, J. (2018)
[13] Revenue-based betas are appropriate for estimating the value of a revenue stream to a private partner, and may be a useful input into the negotiation process.

If one accepts that market risk is a cost to the government, then the common practice by governments of equating their cost of capital to their own borrowing rate ensures a downwardly biased discount rate for all but the safest projects and claims. The size of the bias can differ significantly across projects and claims with different risk exposures. These observations run counter to the perception that using a government rate for discounting is somehow fairer to competing projects, or more reliable because there is no judgment involved. Nevertheless, it is a legitimate concern that giving too much latitude to government analysts in choosing discount rates effectively gives them the ability to manipulate outcomes, and that it is important to preserve transparency in the project evaluation and contracting process. Such concerns can be addressed in a variety of ways while staying true to fair value principles. For instance, governments can set clear guidelines and precedents for establishing discount rates, and the services of a professional valuation practice can be employed to participate in the selection of discount rates or to vet the rates that are chosen.

A further conceptual question is whether discount rates derived from market returns require a tax adjustment when applied to public infrastructure projects. The issue is that market returns are measured prior to personal tax payments on investment income and capital gains. Equilibrium market returns include compensation for the tax liabilities of the marginal investor in each asset class. The returns that accrue to citizens in their role as residual equity holders of public infrastructure projects are not taxable. That suggests a possible downward adjustment to discount rates when considering the project from the perspective of the government. However, the marginal investor in a given asset class is not directly observable. Because of the large market presence of tax exempt investors such as pension funds, and because of the ability to offset capital gains with capital losses, the offset may be small.[14] A different perspective is that the tax free returns to citizens as equity holders in infrastructure projects should be considered a tax expenditure for the government, and hence that its cost to the government offsets its benefit to investors. In the example below, we make no adjustment for this possible effect.

3.3 Summing up: valuing a standalone project

We now have the ingredients for the first step of an APV analysis of a public infrastructure investment, which is to value it as a standalone, all equity financed project, leaving to the side the value of subsidies and financing side effects.

Expected project cash flows are estimated over a horizon of T. For each period t, we denote revenues ρ_t; augmented additional revenues $\rho_{\alpha,t}$; capital expenditures κ_t, periodic costs (e.g., maintenance, salaries, marketing) c_t, augmented additional costs (e.g., tax or pollution externalities) $c_{\alpha,t}$; and the present value of any cash flows beyond T, Γ. As above, $E(r_A)$ is the per period discount rate that reflects the price of risk associated with the net cash flows. Then the NPV of the standalone project can be written as:

[14] See Weber, B., Staub-Bisang, M. and Alfen, H. W. (2016). "Infrastructure as an asset class. [electronic resource] : investment strategy, sustainability, project finance and PPP". Chichester : Wiley, 2016. (The Wiley Finance Series); pg.44.

$$\sum_{t=0}^{T}\frac{\rho_t+\rho_{\alpha,t}-c_t-c_{\alpha,t}-\kappa_t}{\left(1+E(r_A)\right)^t}+\Gamma \tag{2}$$

3.4 Valuing subsidies and financing effects

We now turn to methodologies to find fair values for subsidies and financing effects associated with public infrastructure investments. Those methodologies take into account that the risk characteristics of subsidies and financing effects, and hence the associated cost of capital, is often significantly different from that for the standalone project.

In assigning benefits from tax breaks and other subsidies in a P3 arrangement, it is important to take into consideration that the ultimate beneficiary may not be the private partner. For instance, if there is a competitive bidding process based on minimizing fees, fees plus subsidies will just cover costs, and any increase in subsidy on the margin will offset by a lower fee for infrastructure users.

3.4.1 Cash subsidies, in-kind subsidies, and externalities

Future cash flows arising from cash subsidies, in-kind subsidies, or externalities that are roughly proportional to revenues or variable costs can be discounted at the same rate as the standalone project, on the logic that the associated market risk is roughly similar. However, when cash subsidies are set at contractually fixed levels, or where in-kind subsidies are delivered at a steady level that is independent of use rates, a lower discount rate that reflects the lower beta risk of those flows is appropriate. Other cash subsidies like minimum revenue guarantees are equivalent to put options, and we discuss how to value them with derivative pricing methods below. Similarly, risk properties of externalities determine the appropriate discount rate.

3.4.2 Municipal bonds

A major source of funding for public infrastructure projects in the U.S. is the municipal (muni) bond market. Outstanding municipal issuances totaled \$3.7 trillion in 2018, down from a peak of \$4.1 trillion in 2010. Annual issuances have fluctuated around \$400 billion in recent years, with revenue bonds comprising over half of that total and general obligation bonds accounting for most of the rest of them.[15]

Tax exempt munis are an attractive source of funds for state and local governments and P3s that can access that funding because they are subsidized by the federal government. The subsidy is in the form of a tax exemption on investors' interest income from federal income taxation that increases the value of the bonds and thereby lowers the cost of borrowing. The interest on most municipal bonds is also exempt from the state and local taxes of the issuing jurisdiction.[16]

Those tax exemptions are most valuable to upper income households with high marginal tax rates, which comprise the largest category of investors in munis. The annual reduction in interest

[15] Statistics from the Federal Reserve and Thompson Reuters, as reported by SIFMA.
[16] Pirinski and Wang (2011) show how this feature creates a clientele effect that narrows the investor base and increases the cost of muni financing.

costs associated with the tax exemption from the perspective of borrowers is related to the breakeven tax rate, τ. That tax rate equates the after-tax return on a non-exempt bond, r_T, with the return on a tax exempt muni, r_{TE} with similar credit risk, maturity and liquidity:

$$r_{TE} = r_T(1-\tau) \tag{3}$$

Longstaff (2011) estimates an average breakeven tax rate of 38% using muni swap data from 2001 to 2009, a rate that is close to the maximum statutory rate for that period and consistent with high net worth individuals being the marginal investors. Breakeven tax rates for longer maturity munis have historically been much lower.

From a comprehensive government perspective, the APV of a public infrastructure project is reduced by the present value of all foregone revenues from tax exemptions. At each level of government, the cost depends on the counterfactual assumption about the effect on its tax revenues, E(τ), had the exemption not existed. The annual cost is $P_t \times \mathrm{E}(\tau) \times r_T$, where P_t is the outstanding principal at time t. Discounting those annual flows over the lifetime of the bond at the rate r_T gives the present value cost that can be incorporated into the APV.[17] The counterfactual for E(τ) traditionally was based on the high marginal tax rates of the wealthy households that are the main investors in munis. However, without the tax exemption, many muni investors would choose alternative investments with a more favorable tax treatment. To take that likelihood into account, one possibility is to assume a lower value for τ, based on an average of ordinary income and capital gains rates or based on the observed investment behavior of wealthy households. Poterba and Verdurgo (2011) suggests that could halve the estimated cost relative to basing it on the high marginal tax rates of the wealthy.

Note that the discount rate for muni bond cash flows is almost always lower than the fair value discount rate for the infrastructure project that the bonds are funding. Revenue bonds are much less risky because of equity or guarantee protections. The risk and required return on muni bonds will also depend on their priority in default and other features. As noted earlier, whereas payments on revenue bonds are funded out of project cash flows, general obligation bonds are backed by the taxing authority of the issuer and are generally safer for that reason.

Muni bonds issued at a project's inception may have a maturity that is shorter than the service life of the project. If the bonds will be rolled over into new muni bonds at maturity, the flow of foregone tax revenues and subsidy benefits should be extended to the likely termination date for the final refunding. If refunding is not assured, the cash flows beyond the initial maturity date can be scaled to the probability of refunding.

For infrastructure projects involving P3s, muni bonds may be issued on behalf of a private partner. When they are tax exempt, they are called Qualified Private Activity Bonds. The flow value of the tax advantage to the partner also can be approximated based on the difference between the taxable and tax exempt interest rate times the outstanding principal: $P_t \times \tau \times r_T$. Discounting the flow value at r_T and taking into account possible maturity extensions gives the

[17] Choosing the discount rate based on an equivalent taxable bond imposes consistency in the use of market rates before personal taxes.

present value benefit that can be incorporated into the APV from the perspective of the partner. In addition to conferring a tax advantage, being granted access to muni financing might signal implicit government credit support that further lowers the interest rate, and that additional advantage should also be quantified.

The ultimate beneficiary of the tax break or other subsidies may not be the private partner in a P3 arrangement. For instance, if there is a competitive bidding process over fees, fees plus subsidies will just cover costs (including capital costs), and any increase in tax subsidies will on the margin be offset by a lower fee for infrastructure users.

3.4.3 Debt subsidies and credit guarantees

Even when tax advantaged funding is unavailable, governments may subsidize a partner's cost of funds by (a) guaranteeing loans or debt issues for the partner, or (2) issuing general obligation debt and lending the proceeds to the partner to help fund the project.

Government credit guarantees lower the cost of debt funding by transferring risk from a partner to the government. The value of credit guarantees can be estimated as the difference between the fair value of the promised payments on the debt absent the guarantee, and the fair value of the promised payments with the guarantee. CBO (2011) describes that procedure and applies it to a federal guarantee of infrastructure investments in nuclear power plants. The value of debt absent a guarantee can be inferred from the market price of the partner's unguaranteed debt (also adjusting for maturity effects), or indirectly from its credit rating. Credit guarantees can also be valued as put options (Merton, 1977), but that approach is often more complicated and not described in detail here.

A government may issue public debt and lend the proceeds to a private partner at a rate that is lower than what the partner could borrow at on its own. The subsidy value of such a concessional interest rate is found by discounting the promised cash flows on the concessional loan by the market interest rate available to the partner, and subtracting that present value from the principal of the loan. For example, say the government makes a one-year loan of $1 million to a private partner at a 5% interest rate. Based on the partner's credit rating, it is inferred that it would have borrowed at 6% in the market. Then the present value of the promised loan payment is ($1.05 million)/1.06 = $990,566 and the subsidy is $9,423.

3.4.4 Minimum revenue guarantees

P3 contracts sometimes include clauses that guarantee a minimum stream of revenues to the private partner for some time period (Rouhani et. al., 2018). Its cost to the government and benefit to a private partner can be assessed most accurately by recognizing that the guarantee is a strip of put option on the stream of future revenues. Black's model for pricing commodity options is well suited to this application. The approach can also be used to estimate the ex ante cost of contract renegotiations that are triggered by profitability falling below some threshold, as discussed below.

Black's model, adapted here to value a minimum revenue guarantee, has the following inputs: T is the time to maturity of the option, i.e., the arrival time of the revenue flow; F_T is the forward price of the revenue flow at T; X is the minimum guaranteed revenue, ρ_T is the risk-free rate on a continuous basis for maturity T; σ_T is the standard deviation of time T revenues; N is the cumulative normal distribution; and $p_{0,T}$ is the value of the revenue guarantee for time T as of time 0. Then

$$p_{0,T} = e^{-\rho_T T}\left[XN(-d_2) - F_T N(-d_1) \right] \tag{4}$$

where

$$d_1 = \frac{\ln(F_T / X) + \sigma_T^2 T / 2}{\sigma_T \sqrt{T}} \qquad d_2 = d_1 - \sigma_T \sqrt{T}$$

The forward price F_T is found by calculating the present value of the expected cash flow at time T, discounting at the appropriate risk-adjusted rate, and then bringing that present value back to time T multiplying by $e^{\rho_T T}$.

The calculation also requires estimating the standard deviation of future revenues at each maturity. The standard deviation can be estimated from revenue data on similar projects when such information is available, or on estimates of demand variability. The time subscript on the volatility is included to suggest that there may be more uncertainty about revenues during certain periods, such as in the early years of a long-lived project when the start date of operation is uncertain.

The total value of a minimum revenue guarantee contract is the sum of the individual revenue payment guarantees $\sum_{t=1}^{T} p_{0,t}$.

3.4.5 Renegotiation and implicit guarantees

It is widely recognized (e.g., Engel et. al., 2011) that a major risk for governments engaging in P3s is the high rate of renegotiation with private partners when revenues, costs or timelines fail to meet expectations. The possibility of renegotiation can be viewed as a type of implicit guarantee that transfers value from the government to a private partner if a triggering event occurs. A rough way to incorporate the ex-ante value of such protections is to use the above method for valuing minimum revenue guarantees. The strike price X, could be set to the level of revenue below which additional compensation is likely to be received to top off realized revenues. Another approach would be to value renegotiation as a put option, where the partner would sell back the project to the government for some fixed price were its value to fall below some threshold level.

Private partners similarly bear the risk that the government will renegotiate or default on a contract, and they will require compensation for that risk that similarly can be valued using options pricing approaches. Ideally, contracts will be structured in a way that risk is shared optimally, taking into account the incentive effects of different arrangements (Rouhani et. al.

2018). Engel et. al. (2011) note that having a partner firm face less risk to begin with reduces opportunistic renegotiations.[18]

4. Evaluating a toll road: An example

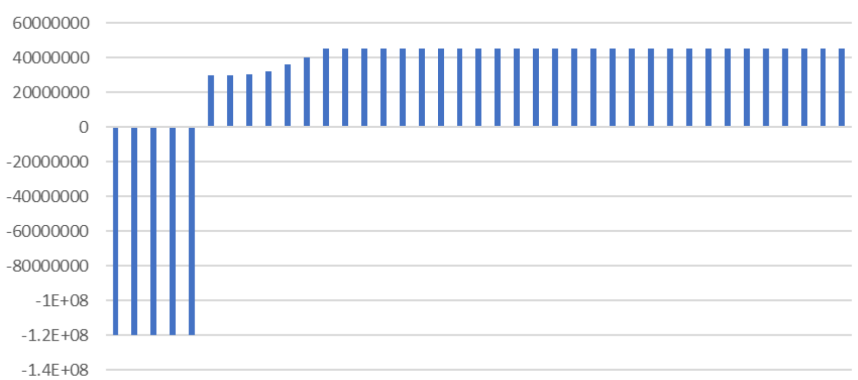
An APV analysis of a hypothetical toll road project structured as a P3 illustrates the sensitivity of valuations to alternative assumptions about discount rates, risk-sharing arrangements, and funding sources. All cash flows and discount rates are in real terms unless otherwise noted.

4.1 Cash flows

The base case cash flows conform to the typical pattern of toll revenues net of capital expenditures, and operating and maintenance costs. Here the project is assumed to start in 2018. The scale of the example project and some of its other features such as its duration are loosely based on projections that were made for the California Highway SR-91 Corridor Improvement Project. The Appendix provides additional information about SR-91, some general lessons from that experience, and other considerations for P3 investors.

In this stylized example, there are five years of large capital investments, followed by the typical S-shaped pattern of net toll revenues reflecting growing demand and profitability that plateaus as capacity is filled (Figure 1). The total project length is 40 years, including five years of construction and a 30-year concession to a private partner.

Figure 1: Toll road cash flows (annual)



For simplicity, the residual value in the 40th year is set to zero. We also abstract from any lumpy capital expenditures beyond the fifth year, implicitly subsuming those costs into smoother operating and maintenance cost flows.

Estimates of the volatility of toll revenues or other components of cash flows are necessary to value minimum revenue guarantees and other options associated with the project. We calibrate volatilities using data from the U.S. Department of Transportation (DOT) on 15 toll roads and

[18] They advocate present value revenue contracts instead of taking the lowest fee bidder as a way to make buying back a project when necessary easier, but also note the shortcoming that without upside revenue for partner there is no incentive to encourage demand.

bridges for which fairly complete toll revenue data is available from 1998 to 2016 (Table 2).[19] For nominal (real) toll revenues, the coefficient of variation averages 0.30 (0.40), with a standard deviation of 0.14 (0.13). Whether the relevant variation is real or nominal depends on the terms of the contract being valued. From the perspective of the contracting parties, the variability for an individual project should be lower than what is estimated here because some of the variation is likely to be foreseeable, e.g., because of projected growth in demand over time. The variability is also likely to be higher in earlier years and lower in later years when the road is at capacity and there is less uncertainty about the timing of the completion of construction.

4.2 Cost of capital

We calculate the value of the standalone project using a discount rate based on an estimate of the asset beta for toll roads, and returns data from 2018. For comparison we report the value of the standalone project discounting with a long-term muni bond rate of 1.72% (real), which in 2018 happens to be close to the median choice for the social discount rate of 2% (real), as reported in a recent survey of economists (Drupp et. al., 2018). We also compare the results using the current 7% Office of Management and Budget (OMB) circular A94 guidance rate for federal investment projects.[20]

We choose the asset beta from Table 1, using the 2018 average value between transportation (0.8) and trucking 0 (.81) which is 0.805. Setting the short-term risk-free rate at 2% and the equity premium to 6% implies a nominal discount rate of .02 + .805(.06) = 6.8%. We assume that expected inflation is 2%, which is consistent with the Federal Reserve's target. That implies a real fair value discount rate of 4.7%. We take this to be the correct rate for discounting net project cash flows and toll revenues.[21]

As discussed earlier, a government might incorrectly identify its cost of capital with its borrowing rate, which for the state and local governments sponsoring road projects is usually a municipal bond rate. Data from the Bond Buyer 20-Bond GO Index, which tracks rates on a portfolio of 20-year general obligation bonds rated AA by Standard & Poor's or Aa2 by Moody's, suggests that nominal rates averaged around 3.75% between 2010 and 2019. Adjusting for expected inflation implies a real long-term muni rate of 1.72%.

4.3 Value of standalone toll road project

Discounting the Figure 1 real cash flows at the real CAPM or risk-adjusted discount rate of 4.7% implies that the standalone project has a positive NPV of $36.7 million. As shown below, adding

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[19]Historical data on toll roads from the DOT is the source of all data-based inferences on cash flows unless otherwise stated. https://www.fhwa.dot.gov/policyinformation/statistics.cfm

[20] Circular 94 allows for some flexibility to accommodate market rates that differ from the 7% real rate assumption, but suggests that deviations should be rare.

[21] We attempted for comparison purposes to estimate betas based on the correlation of toll revenues with market returns from the 15 projects used to estimate volatility, but the data is insufficient to produce reliable estimates.

in any subsidies, financial side effects, guarantees and externalities could reverse or add additional support for the conclusion that the project adds value.

The estimated NPV increases by an order of magnitude to $450.9 million using the real muni rate of 1.72% for discounting. (Using a social discount rate unadjusted for risk of 2% would lead to a similarly inflated conclusion.) Using the OMB rate of 7% implies an NPV of -$117.5. The very large differences in outcomes are attributable to the long life of the project and the low level of market rates.

A useful point of reference is the internal rate of return (IRR) of the project, which is 5.703%. Any assumed discount rate lower than that will result in a positive NPV for the standalone project, and conversely for a discount rate that is below it.[22] Under our preferred discount rate the project in itself creates value. We turn now to how financing side effects might change that conclusion.

4.4 Incorporating subsidy and financing cost side effects

We consider how minimum revenue guarantees, the cost of the municipal bond tax exemption, and the possibility of positive externalities from decreased congestion on other roads can be incorporated into the analysis to produce an APV for the toll road.

4.4.1 Minimum revenue guarantees

P3s may include minimum revenue guarantees to protect partners against unanticipated shortfalls in revenues or increases in cost. An accurate estimate of the value of such guarantees is an important input into an APV analysis, and also a useful bargaining tool for governments when negotiating a contract with private partners. We will see that the value of those guarantees can be considerable. The cost to the government may be justified when gains from improved operating efficiencies, faster construction schedules, lower toll charges, or other benefits that a private partner might deliver in return for the guarantee exceed its cost.

The value of a minimum revenue guarantee will vary with the floor revenue, revenue volatility and the lifetime of the guarantee. In Table 3 we report the results of using Black's model to calculate guarantee values for the toll road example, with and without risk adjustment, and for a range of assumed contract terms (see section 3.4.4 for formulas used). Specifically, we consider floors on annual revenues of $15 million and $30 million (versus the $64.8 million steady state projected revenues), and guarantees with durations of 5, 10 and 20 years. To capture the greater uncertainty about revenues in early years, we consider a declining term structure of forward price volatilities ranging from a multiple of .5 for the first two years of operation ramping down to .2 for years 6 of operation and beyond. We also consider a flat volatility of .3. The risk-free rate is fixed at 2%.

With risk adjustment, the estimated revenue guarantee values range from a low of $5.3 million for a 5-year $15 million minimum annual revenue with volatility of .3, to a high of $152 million for a 20-year $30 million minimum annual revenue and volatility of .3. The range of values is

[22] The IRR is unique in this example and can be used in this way because the cash flows only change sign once.

slightly narrower ($12.8 million to $121.4 million) under the assumption of declining volatility. Recall that the standalone NPV for the project is $36.7 million. These estimates demonstrate that minimum revenue guarantees can flip the APV of a project from positive to negative, even when they are far out of the money, as in the case of the $15 million floor relative to the $64.8 million in expected steady state revenues.

The inputs into the Table 3 estimates without risk adjustment are identical to those with risk adjustment except for the forward prices of future revenues. Neglecting risk adjustment significantly biases down the estimated guarantee costs. For example, for a 20-year guarantee of a $30 million floor, under either volatility assumption, the guarantee value is more than $42 million higher when the cost of risk is taken into account. That difference is greater than the NPV of the standalone project.

4.4.2 Subsidies from municipal bond and TIFIA financing

Debt has reportedly been used to fund approximately 70% of road construction projects in recent years. Subsidies are conveyed via tax advantages, credit support, or a combination of the two. General obligation, revenue, and private activity municipal bonds are the main sources of tax advantages. Direct or guaranteed loans made under the federal Transportation Infrastructure Financing and Innovation Act (TIFIA) program is the main source of federal credit support.[23] State and local governments may also provide credit support.

Here we assume that the $600 million in capital expenditures over the first 5 years of the project is funded with debt issuances that total $420 million, and that the remaining $180 million of investment is funded with equity raised by the private partner at a fair market price. We assume that TIFIA guarantees $120 million of the debt, special activity muni bonds fund $230 million, and the balance of $70 million is covered by unsubsidized private partner debt.

A TIFIA guarantee provides full faith and credit backing from the U.S. government on debt with maturities of up to 35 years, for qualifying projects that are substantially complete. With a TIFIA guarantee, the borrowing rate should be only slightly higher than the Treasury rate for a corresponding maturity (and may be lower if the debt is also tax exempt). The (nominal) market interest rate on the same debt without the TIFIA guarantee would depend on the underlying project risk, the priority of the debt in the project's capital structure and any recourse provisions, the total leverage, and a variety of other factors. A project's credit rating reflects those risk drivers, and when available is a useful indicator of the market rate that would be attainable absent guarantees.

To provide a sense of the magnitude of a TIFIA subsidy, we assume that the TIFIA-backed debt is taken out in the 5th and last year of construction, and amortizes over a 30-year maturity, with level payments of principal repayment and interest to investors. The interest rate is taken to be 2.25%, 25 bps over the risk-free rate in this example. We further assume that the debt on the standalone project would be rated BB by S&P, slightly below investment grade. In 2018 the

[23] TIFIA credit assistance is limited to 33% of eligible project costs (or up to 49% under compelling justification by sponsor). For a general overview see: https://www.transportation.gov/tifia/tifia-credit-program-overview

spread over the Treasury rate for BB bonds was at a historically low level of approximately 2.25%. Adding this to the 2% risk-free rate implies an interest rate of 4.25% absent the guarantee. As described in section 3.4.3, we calculate the present value of the credit subsidy as the difference between the present value of the promised debt payments discounted at the subsidized borrowing rate of 2.25% (the principal value of the loan) and the estimated market rate of 4.25%. The resulting subsidy as of year 5 when the debt is issued is $27 million, or 22% of the $120 million of guaranteed debt. Discounting the subsidy to time zero at the 4.25% rate implies a present value subsidy of $22 million.[24]

We assume that the $230 million of muni financing is issued at time 0, and that the principal will not be repaid until the 40th year. The initial maturity of the muni debt issued is likely to be shorter, but if the debt is rolled over at each maturity date then the tax advantage can continue over the life of the project. Because the debt will be outstanding over the riskier construction phase of the project, we assume that without the tax advantage it would carry an interest rate of 4.75%, which is higher than on the unguaranteed equivalent of the TIFIA bonds. We assume that the breakeven tax rate is 20%, providing apparent annual interest savings of $230mm(.0475)(.2). Discounting the flow savings at a 4.75% discount rate over 40 years gives a present value subsidy from the tax exemption of $39 million.[25]

The subsidies in this example are a cost to the federal government. A state or local government that is undertaking an APV analysis of the project might treat them as adding to the APV of the project. However, from a broad taxpayer perspective, they represent a transfer of value from federal to state and local taxpayers. Furthermore, to the extent that they are passed through to private partners in a P3 and the value is not recuperated through the bidding process or other contractual provisions, the subsidies have a net cost to taxpayers overall.

4.5 Incorporating the value of positive externalities

The assessed value of the stand-alone project would be significantly higher if significant positive externalities that were factored in. Users of nearby highways might also benefit from reduced congestion and travel times. Consumer surplus might exceed tolls paid. Those types of benefits are likely to be roughly proportional to revenues, and their value can be calculated by applying a multiplier to projected cash revenues and discounting at the standalone project discount rate of 4.7%. In this example, increasing revenues by 10% adds $78 million to the APV. That additional estimated value increases to $145 million if it is evaluated using the real muni rate of 1.72% as the cost of capital.

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[24] This treats the risk of the subsidy over the first five years as equal to the risk of the debt issued in the 5th year. A more conservative assumption would be to treat the risk as similar to the risk of the project. Note too that in these calculations of debt subsidies we are discounting nominal debt payments at nominal rates rather than converting market data to real terms.

[25] A subtlety is that the apparent savings to the sponsoring government may exceed the cost to the federal government. As discussed earlier, the cost to the federal government may be lower than suggested by the breakeven tax rate because of asset substitution. The interest savings to the sponsor, however, is unaffected by asset substitution.

4.6 Adding it all up

Table 4 summarizes the results of the APV analysis of a hypothetical toll road on a fair value basis, from a taxpayer perspective that includes financing subsidies as a cost. It also reports a cost estimate with the same elements, but without risk adjustment and treating credit subsidies as free. The results are starkly different: The APV on a fair value basis is -$13.7 million, whereas it rises to $544.3 million in the absence of risk adjustment and subsidy cost recognition.

The difference in estimated value is primarily the result of the higher discount rate used in the fair value analysis. It would be even larger if the minimum revenue guarantee were overlooked entirely in accounting for costs.

5. Funding and budgetary considerations

The analysis thus far has assumed that infrastructure investments are taking place in a well-functioning capital market, and that subsidies are available for some forms of funding and not for others. Those assumptions are appropriate for the U.S., where most state and local governments have access to capital markets or banks, and where municipal bond financing is widely available. Probably in part because of those factors, P3s have been less popular than in other parts of the world where they may improve government access to capital. Table 5 shows the breakdown of funding and revenue models for a sample of U.S. transportation projects, as reported by the DOT. P3s are involved in 47 out of the 191 projects in the dataset, but 35 out of the 47 also use project finance, and 24 of the 47 participate in TIFIA. In fact a stated goal of TIFIA is to support private sector participation in infrastructure investments.

However, some view limited availability of funding to be a significant impediment to U.S. investment in necessary infrastructure. To address that issue, proposals have been put forward to create a federal infrastructure bank to increase funding for and improve the selection of projects, particularly for surface transportation. CBO (2012a) analyzes a stylized version of the leading proposals and makes several important observations. A technical impediment to creating an infrastructure bank at the federal level is that a revolving fund structure is not feasible under U.S. budgetary rules; funding would have to be reauthorized annually. More fundamentally, advocates for creating an infrastructure bank are often more concerned with increasing subsidies than with increasing funding access. CBO observes that subsidies could be increased by expanding TIFIA or through other credit subsidy programs. However, to understand the full cost of such expanding existing credit subsidy mechanisms, it is important to understand that under the Federal Credit Reform Act of 1990, reported credit subsidies do not take into account the cost of risk and hence understate the full value of the subsidies (Lucas, 2012).

Relatedly, in an analysis of the effect of P3s on transportation funding, CBO (2012b) finds that private financing will increase the availability of funds for highway construction only in cases in which governments restrict their spending by imposing legal constraints or budgetary limits on themselves. This highlights that restrictions such as balanced budget rules at the state level may impede infrastructure spending, particularly for major maintenance that is not classified as a capital expenditure that may have some additional budgetary flexibility.

The absence of capital budgets in some jurisdictions, notably at the federal level, is sometimes cited as a budgetary impediment to infrastructure funding. When budgeting is done entirely on a cash basis, the large upfront cost of many infrastructure investments may discourage lawmakers from authorizing the funds. Proponents of capital budgets or rules that would spread upfront expenditures over the service life of the project believe that such changes would reduce legislative impediments to funding large infrastructure projects. Opponents to such changes argue that budget transparency dictates that the full cost of spending be reported upfront when the obligation is incurred. They also observe that in the federal context even very large projects have a negligible effect on federal budget totals, although that is less true at the agency level.

6. Concluding remarks

We have emphasized the importance of incorporating the effect of risk on value in assessing public infrastructure investments and associated financial contracts and subsidies, and shown how leading private sector valuation approaches can be adapted for public sector analyses. An extended example of a toll road project highlights a more general conclusion: The value of long-lived projects may be over-estimated by an order of magnitude when the cost of risk is ignored, as is often the case in analyses of public infrastructure. The example also illustrates how investment decisions can be distorted significantly by applying a one-size-fits-all discount rate across a range of projects and contracts that have widely different risk characteristics.

An original contribution of this chapter is to establish that the ex-ante or prospective cost of minimum revenue guarantees for private partners, and of contract renegotiations when profits fall below some threshold, can be estimated using Black's model for valuing commodity options. An options pricing approach accounts for the magnification of market risk associated with such guarantees, and hence makes clear the significant value transfers that guarantees often entail. Adopting this approach would help governments to better understand the value proposition in P3 and other arrangements with private partners. That information could improve governments' bargaining position, and make it easier to avoid entering into contracts where renegotiation is likely to be costly.

On the financing side, we note the prevalence of credit subsidies in the U.S. that are delivered via the municipal bond market, and to a lesser extent by federal credit programs. The wide availability of this "low-cost" funding may partially explain the lower incidence of P3s in the U.S. than in many other countries. Nevertheless, state and local governments rely heavily on private partners, and hence the analysis of contractual value transfers is relevant for many of those arrangements. From a cost-benefit perspective, it is important to account for the subsidy cost to federal taxpayers of credit subsidies, whatever the delivery vehicle. Those costs generally offset the financial benefit to state or local governments, but are often neglected in the evaluation process by non-federal project sponsors.

Finally, a major impediment to more accurate project evaluations is the lack of project level historical data on cost and performance. Devoting additional federal resources to data collection, standardization, and dissemination could provide an important public good to support better decision-making by public sector project managers.

Appendix

Here we provide additional information on the California Highway SR-91 project, some of the broader lessons illustrated by this example, and additional considerations for investors in P3s.

Reference projections for SR-91 were prepared by Stantec, the authority's traffic and revenue consultant. A comparison of two of those preliminary studies reveals variations in toll revenue forecasts as large as 1.03x (average 0.18) from one estimation to the other. [26] This highlights an important lesson and persistent challenge in infrastructure projects as shown in Bain (2009) and Flyvbjerg (2005) : the need to reduce uncertainty (and inaccuracy) in toll road traffic forecasts used for project valuation. In this type of deal, investors ponder whether the risks they might bear are compensated by the financial returns based on these analyses. In the case of SR 91, demand exceeded initial expectations in its first operation years; however, it is noteworthy to mention that these preliminary forecasts defined the contract terms and risk allocation between private during the contracting process.

Typically, infrastructure P3 projects involve an initial amount of financial capital (i.e. debt and equity) set by the private partner to design, build, expand, upgrade, and/or operate the assets stipulated in the contract. This investment can be complemented with different types of public sector support (e.g. direct subsidies, guarantees, etc.). Construction costs tend to be large upfront investments, while operation and maintenance (O&M) represent a relatively smaller proportion of total costs. These costs are intended to be recovered (usually with a return) through payments in the form of: user-fees, public sector payments, or a combination of both. The risk profile, rights, and obligations assumed by each party vary from deal to deal and are determined by the type of project and P3 format chosen. [27] At the end of the contract, the assets are usually transferred back to public sector ownership.[28] When a project becomes operational (e.g., the year a new, toll road opens and starts to collect tolls), the demand is expected to go through a ramp-up period in its first years (usually with higher volatility). Demand fluctuations would be expected to stabilize, ceteris paribus, as the road matures, and it approaches physical capacity. Hence, we would expect an s-shaped growth profile as asset reaches maturity (Figure A1).

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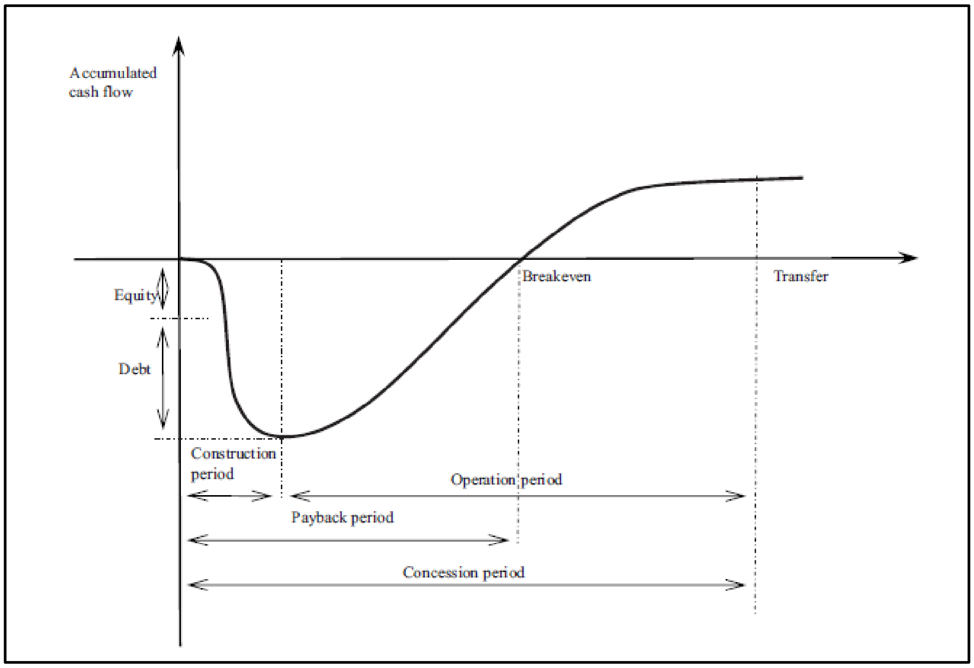
[26] Document 1: Orrick, Herrington & Sutcliffe LLP (2013). "Riverside County Transportation Commission: toll revenue senior lien bonds". pg. 65. USA. https://emma.msrb.org/EA546917-EA426056-EA822989.pdf

Document 2: Riverside County Transportation Commission (2013). "SR-91 Corridor Improvement Project: Toll Revenue Bonds 2013, 2013 Series A and Series B". Rating Presentation; pg. 20. California, USA

[27] For instance, project size and maturity, stand-alone or network asset, urban infrastructure, and existing/potential competition can impact a project's risk profile. See a discussion on the relevance of these and other asset features in: Fitch Ratings (2017). "10 Years in Infrastructure: Toll Roads (Report)." New York, USA. https://your.fitchratings.com/Toll-Roads-10-Years-in-Infrastructure.html

[28] For a more detailed description of the life cycle of a PPP, including self-contained structures like project finance/SPVs see: Engel, E., Fischer, R. and Galetovic, A. (2014b). "*Finance and Public-Private Partnerships*" https://www.rba.gov.au/publications/confs/2014/pdf/conf-vol-2014.pdf

Figure A1: Typical cash flow profile for a DOT project



Source: Zhang (2009).

Table 1: Asset Betas by Industry

Table 1: Asset Betas by Industry

				Unlevered Betas corrected for cash - Over time				
Industry Name	**Number of firms**	**Beta**	**2019 Unlevered beta corrected for cash**	**2015**	**2016**	**2017**	**2018**	**Average (2015-19)**
Air Transport	18	1.02	0.63	0.61	0.85	0.76	0.67	0.70
Engineering/Construction	52	1.01	0.81	1.19	1.07	1.01	1.13	1.04
Green & Renewable Energy	21	1.62	0.80	0.68	0.84	0.47	0.72	0.70
Homebuilding	31	0.98	0.72	0.92	0.81	0.77	0.89	0.82
Hospitals/Healthcare Facilities	34	1.12	0.55	0.59	0.44	0.45	0.51	0.51
Power	51	0.54	0.35	0.53	0.50	0.33	0.32	0.41
Real Estate (Development)	18	1.19	0.87	0.82	0.93	0.47	0.61	0.74
Shipbuilding & Marine	9	1.08	0.78	0.94	0.84	0.85	1.01	0.89
Transportation	19	1.14	0.90	0.77	1.19	0.83	0.80	0.90
Trucking	28	1.22	0.71	0.92	1.03	0.76	0.81	0.84
Utility (General)	18	0.27	0.17	0.42	0.36	0.25	0.20	0.28
Utility (Water)	19	0.42	0.32	0.77	0.33	0.47	0.27	0.43
Total Market	7209	1.12	0.80	0.70	0.73	0.65	0.72	0.72
Total Market (without financials)	6004	1.21	1.00	0.87	0.9	0.85	0.90	0.90

Source: http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/Betas.html

Table 2: Sample toll projects with DOE data

Table 2. Sample toll projects with DoT data (selected variables; 1999-2016)

Further information on these and other U.S. toll roads can be accessed in the dashboard we have prepared in the following link: https://datastudio.google.com/s/n_R2ZaE9zqs

Toll revenues

facility_name	state	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biscayne Key (Rickenbacker) Causeway	Florida	5,067.00	5,302.00	5,649.00	5,805.00	6,938.00	6,627.00	5,418.00	6,040.00	8,083.00	8,582.00	NA	9,195.00	NA	NA	9,709.00	10,912.00	NA	7,943.00
Cameron County International Toll Bridge	Texas	7,697.00	8,942.00	11,541.00	12,398.00	13,595.00	15,124.00	16,086.00	15,814.00	17,867.00	17,369.00	NA	4,302.00	NA	NA	16,745.00	14,850.00	NA	14,700.00
E-470 Beltway	Colorado	3,169.00	12,612.00	24,657.00	36,266.00	37,121.00	59,855.00	73,733.00	78,943.00	91,730.00	95,435.00	NA	90,486.00	NA	NA	118,717.00	132,106.00	132,106.00	183,909.00
Eagle Pass-Piedras Negras International Bridge	Texas	5,276.00	5,797.00	7,390.00	7,080.00	7,295.00	7,877.00	7,901.00	8,019.00	7,784.00	8,654.00	NA	8,115.00	NA	NA	7,838.00	8,043.00	NA	10,368.00
Foothill/Eastern Toll Roads	California	5,810.00	34,452.00	56,441.00	74,549.00	79,504.00	83,156.00	91,885.00	103,043.00	106,610.00	116,648.00	NA	103,907.00	NA	NA	123,945.00	129,005.00	NA	152,022.00
Golden Gate Bridge	California	58,124.00	58,453.00	59,369.00	59,180.00	59,289.00	79,427.00	86,393.00	80,445.00	85,479.00	80,456.00	NA	93,077.00	NA	NA	103,779.00	106,977.00	NA	138,321.00
Laredo-Nuevo Laredo International Bridge	Texas	21,917.00	26,147.00	28,748.00	28,548.00	31,342.00	32,436.00	33,272.00	33,366.00	39,047.00	38,141.00	NA	40,644.00	NA	NA	45,068.00	44,735.00	NA	57,320.00
Lee County Toll Bridges	Florida	24,234.00	26,321.00	27,763.00	29,162.00	30,235.00	31,924.00	33,581.00	44,110.00	42,253.00	41,187.00	NA	37,483.00	NA	NA	37,765.00	39,174.00	NA	43,838.00
McAllen International Toll Bridge	Texas	7,576.00	8,345.00	8,479.00	9,838.00	9,869.00	10,221.00	10,223.00	11,058.00	11,256.00	10,533.00	NA	11,187.00	NA	NA	12,977.00	13,232.00	NA	14,192.00
Osceola Parkway	Florida	4,871.00	6,120.00	7,255.00	7,529.00	6,586.00	7,056.00	2,253.00	11,710.00	9,937.00	10,802.00	NA	10,356.00	NA	NA	11,632.00	11,550.00	NA	13,995.00
Richmond Expressway System	Virginia	19,861.00	22,707.00	23,204.00	24,210.00	24,865.00	24,825.00	25,483.00	25,048.00	25,577.00	25,099.00	NA	33,191.00	NA	NA	36,307.00	36,551.00	NA	38,872.00
San Joaquin Hills Toll Road	California	35,009.00	42,032.00	46,582.00	51,634.00	57,734.00	63,379.00	70,145.00	79,250.00	86,464.00	94,349.00	NA	91,812.00	NA	NA	102,508.00	109,938.00	NA	166,374.00
Tacony-Palmyra and Burlington-Bristol Bridges	New Jersey	15,161.00	15,963.00	26,803.00	29,230.00	31,206.00	26,218.00	28,335.00	28,749.00	29,148.00	29,036.00	NA	30,455.00	NA	NA	33,545.00	33,567.00	NA	33,712.00
Woods Hole, Martha's Vineyard and Nantucket Fer	Massachusett	27,797.00	24,498.00	32,787.00	54,858.00	59,895.00	55,402.00	57,656.00	59,366.00	64,737.00	70,786.00	NA	71,033.00	NA	NA	75,697.00	79,787.00	NA	88,560.00
Zaragosa Bridge	Texas	11,539.00	11,472.00	12,377.00	12,152.00	10,130.00	10,766.00	11,651.00	13,841.00	14,262.00	14,093.00	NA	14,551.00	NA	NA	15,983.00	17,581.00	NA	20,952.00

Operation costs

facility_name	state	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biscayne Key (Rickenbacker) Causeway	Florida	2,976.00	1,216.00	1,878.00	1,743.00	2,841.00	2,951.00	2,388.00	3,055.00	3,630.00	3,723.00	3,988.00	4,301.00	4,114.00	4,002.00	3,613.00	(1,132.00)	NA	7,172.00
Cameron County International Toll Bridge	Texas	1,442.00	1,896.00	2,587.00	2,869.00	3,062.00	3,112.00	3,485.00	3,739.00	3,436.00	3,314.00	384.00	4,248.00	4,775.00	2,397.00	3,972.00	2,411.00	NA	3,700.00
E-470 Beltway	Colorado	5,194.00	9,536.00	8,412.00	14,715.00	18,476.00	14,820.00	23,563.00	16,676.00	19,805.00	28,989.00	22,968.00	25,937.00	28,270.00	25,974.00	23,823.00	27,806.00	NA	33,335.00
Eagle Pass-Piedras Negras International Bridge	Texas	647.00	657.00	1,065.00	583.00	716.00	809.00	744.00	746.00	910.00	1,102.00	1,253.00	1,063.00	1,078.00	1,135.00	1,380.00	1,431.00	NA	1,115.00
Foothill/Eastern Toll Roads	California	3,992.00	8,998.00	9,744.00	5,524.00	4,505.00	2,617.00	2,015.00	2,959.00	15,364.00	14,154.00	17,190.00	15,572.00	13,169.00	719.00	12,910.00	12,507.00	NA	30,708.00
Golden Gate Bridge	California	8,380.00	8,789.00	9,703.00	12,669.00	11,736.00	16,365.00	17,603.00	9,706.00	17,308.00	20,731.00	21,212.00	17,138.00	14,081.00	35,591.00	23,335.00	16,196.00	NA	122,606.00
Laredo-Nuevo Laredo International Bridge	Texas	13,961.00	12,853.00	21,518.00	18,193.00	24,265.00	19,601.00	19,911.00	25,735.00	29,726.00	31,837.00	34,086.00	31,975.00	33,236.00	32,983.00	34,028.00	34,380.00	NA	41,068.00
Lee County Toll Bridges	Florida	8,266.00	2,044.00	4,269.00	3,459.00	4,039.00	4,539.00	4,444.00	4,665.00	4,767.00	4,690.00	4,297.00	4,997.00	3,865.00	3,693.00	3,675.00	13.00	NA	3,725.00
McAllen International Toll Bridge	Texas	1,350.00	1,312.00	1,367.00	1,251.00	1,773.00	1,811.00	1,448.00	1,711.00	2,246.00	2,727.00	2,542.00	2,300.00	2,774.00	2,899.00	3,351.00	3,083.00	NA	3,310.00
Osceola Parkway	Florida	1,318.00	1,717.00	1,287.00	1,766.00	1,240.00	1,678.00	327.00	63.00	66.00	73.00	83.00	87.00	96.00	42.00	71.00	45.00	9.00	13.00
Richmond Expressway System	Virginia	3,514.00	3,061.00	3,365.00	4,786.00	4,328.00	2,852.00	4,746.00	3,782.00	7,604.00	2,544.00	6,888.00	10,720.00	10,179.00	10,426.00	18,268.00	10,090.00	NA	9,617.00
San Joaquin Hills Toll Road	California	1,096.00	1,003.00	470.00	1,092.00	1,376.00	1,466.00	994.00	1,302.00	9,943.00	10,260.00	10,729.00	10,485.00	10,119.00	9,869.00	10,499.00	9,878.00	NA	15,723.00
Tacony-Palmyra and Burlington-Bristol Bridges	New Jersey	1,883.00	1,844.00	1,949.00	1,897.00	2,091.00	2,454.00	8,530.00	8,388.00	11,515.00	12,025.00	12,544.00	12,637.00	4,500.00	14,798.00	14,801.00	15,004.00	NA	14,617.00
Woods Hole, Martha's Vineyard and Nantucket Fer	Massachusett	22,151.00	22,554.00	23,179.00	25,697.00	25,720.00	27,652.00	28,721.00	28,611.00	29,498.00	31,099.00	36,112.00	29,438.00	31,289.00	34,138.00	32,148.00	32,490.00	NA	33,565.00
Zaragosa Bridge	Texas	655.00	918.00	1,039.00	1,694.00	1,645.00	1,862.00	1,776.00	1,868.00	2,431.00	2,275.00	3,055.00	4,082.00	3,093.00	2,204.00	4,609.00	3,559.00	NA	5,749.00

Maintenance costs

facility_name	state	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biscayne Key (Rickenbacker) Causeway	Florida	-	102.00	53.00	109.00	-	-	194.00	294.00	-	235.00	243.00	-	-	-	-	-	NA	NA
Cameron County International Toll Bridge	Texas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NA	NA
E-470 Beltway	Colorado	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NA	NA
Eagle Pass-Piedras Negras International Bridge	Texas	27.00	27.00	44.00	146.00	202.00	228.00	210.00	210.00	-	-	-	-	-	-	-	-	NA	NA
Foothill/Eastern Toll Roads	California	631.00	1,304.00	1,239.00	1,818.00	3,326.00	3,053.00	3,402.00	3,213.00	3,619.00	3,350.00	580.00	3,491.00	3,431.00	3,315.00	3,339.00	3,345.00	NA	1,566.00
Golden Gate Bridge	California	8,559.00	8,966.00	9,456.00	10,814.00	10,809.00	12,088.00	13,003.00	13,853.00	14,025.00	14,632.00	16,221.00	15,301.00	17,589.00	18,277.00	19,226.00	20,006.00	NA	45,525.00
Laredo-Nuevo Laredo International Bridge	Texas	-	-	-	5,131.00	-	5,528.00	5,616.00	-	-	-	-	-	-	-	-	-	NA	NA
Lee County Toll Bridges	Florida	363.00	128.00	205.00	205.00	343.00	352.00	-	-	-	-	-	-	-	-	-	-	NA	NA
McAllen International Toll Bridge	Texas	79.00	77.00	80.00	353.00	501.00	511.00	408.00	483.00	-	-	-	-	-	-	-	-	NA	NA
Osceola Parkway	Florida	312.00	3,700.00	297.00	403.00	345.00	377.00	109.00	-	-	-	-	-	-	-	-	-	NA	NA
Richmond Expressway System	Virginia	2,523.00	2,785.00	3,181.00	6,068.00	1,267.00	2,005.00	1,761.00	1,516.00	2,729.00	3,319.00	4,865.00	10,202.00	5,004.00	4,233.00	6,199.00	5,577.00	NA	3,922.00
San Joaquin Hills Toll Road	California	830.00	874.00	576.00	1,234.00	1,634.00	1,388.00	1,495.00	1,397.00	517.00	-	-	-	-	-	-	-	NA	5,465.00
Tacony-Palmyra and Burlington-Bristol Bridges	New Jersey	3,503.00	2,100.00	2,313.00	2,335.00	2,556.00	2,635.00	4,047.00	3,469.00	2,288.00	1,864.00	7,391.00	7,882.00	11,905.00	5,166.00	7,548.00	2,273.00	NA	7,120.00
Woods Hole, Martha's Vineyard and Nantucket Fer	Massachusett	5,926.00	5,607.00	6,083.00	6,395.00	9,000.00	8,046.00	8,787.00	9,283.00	10,985.00	10,085.00	11,756.00	12,087.00	9,530.00	9,123.00	10,165.00	14,744.00	NA	17,051.00
Zaragosa Bridge	Texas	36.00	-	-	478.00	464.00	-	501.00	527.00	-	-	-	-	-	-	-	-	NA	NA

Capital outlay costs*

facility_name	state	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biscayne Key (Rickenbacker) Causeway	Florida	97.00	90.00	1,001.00	83.00	1,243.00	1,418.00	1,964.00	1,105.00	582.00	2,104.00	1,812.00	4,725.00	8,089.00	7,193.00	5,566.00	6,364.00	NA	4,568.00
Cameron County International Toll Bridge	Texas	6,263.00	4,028.00	541.00	1,155.00	1,275.00	1,652.00	1,470.00	685.00	123.00	1,163.00	912.00	2,378.00	361.00	4,857.00	1,670.00	2,742.00	NA	685.00
E-470 Beltway	Colorado	98,479.00	60,602.00	48,376.00	134,694.00	115,520.00	28,604.00	14,865.00	34,952.00	20,583.00	12,360.00	5,033.00	15,076.00	2,599.00	3,120.00	12,237.00	4,237.00	NA	7,536.00
Eagle Pass-Piedras Negras International Bridge	Texas	7,168.00	12,802.00	253.00	-	-	-	1,237.00	1,154.00	1,377.00	349.00	325.00	30.00	20.00	-	363.00	118.00	147.00	549.00
Foothill/Eastern Toll Roads	California	318,927.00	225,029.00	56,287.00	18,771.00	25,567.00	30,688.00	33,598.00	23,855.00	46,855.00	69,092.00	66,533.00	60,394.00	21,181.00	22,573.00	13,590.00	15,659.00	NA	38,095.00
Golden Gate Bridge	California	8,910.00	20,395.00	33,307.00	29,281.00	32,029.00	53,972.00	67,209.00	41,009.00	20,812.00	39,395.00	18,179.00	29,704.00	51,612.00	47,550.00	63,206.00	37,395.00	NA	61,986.00
Laredo-Nuevo Laredo International Bridge	Texas	2,346.00	32,847.00	24,940.00	8,963.00	1,514.00	2,717.00	3,090.00	7,091.00	15,817.00	5,487.00	5,037.00	2,126.00	830.00	3,434.00	1,168.00	884.00	NA	1,665.00
Lee County Toll Bridges	Florida	13,254.00	8,615.00	2,773.00	1,675.00	6,010.00	2,189.00	11,170.00	69,260.00	58,096.00	49,489.00	11,242.00	5,799.00	3,594.00	6,256.00	5,207.00	2,760.00	453.00	283.00
McAllen International Toll Bridge	Texas	101.00	66.00	273.00	-	-	571.00	779.00	1,763.00	380.00	5,483.00	18,755.00	17,062.00	1,798.00	742.00	8.00	1,651.00	235.00	984.00
Osceola Parkway	Florida	3,128.00	32.00	-	-	-	-	-	1,085.00	279.00	164.00	248.00	36.00	-	-	-	-	NA	NA
Richmond Expressway System	Virginia	260.00	3,882.00	1,823.00	511.00	596.00	302.00	1,687.00	4,442.00	3,393.00	8,901.00	7,622.00	-	-	-	-	-	NA	NA
San Joaquin Hills Toll Road	California	21,040.00	9,340.00	11,231.00	5,202.00	8,226.00	9,852.00	3,688.00	996.00	1,392.00	2,440.00	2,362.00	6,497.00	8,865.00	563.00	520.00	1,215.00	NA	119.00
Tacony-Palmyra and Burlington-Bristol Bridges	New Jersey	-	-	-	-	-	3,335.00	1,667.00	1,964.00	1,330.00	1,150.00	3,281.00	1,272.00	2,328.00	11,326.00	11,667.00	11,929.00	NA	8,516.00
Woods Hole, Martha's Vineyard and Nantucket Fer	Massachusett	5,796.00	9,283.00	6,632.00	5,270.00	2,429.00	1,985.00	4,513.00	20,158.00	26,585.00	15,653.00	17,604.00	12,831.00	15,583.00	8,905.00	10,949.00	6,370.00	NA	33,070.00
Zaragosa Bridge	Texas	404.00	46.00	1,106.00	404.00	-	798.00	4,036.00	715.00	218.00	391.00	281.00	74.00	1,616.00	6,865.00	6,293.00	2,800.00	3.00	135.00

Source: https://www.fhwa.dot.gov/policyinformation/statistics.cfm

* Capital outlay includes 17 improvement types. These improvement types are allocated among 3 broad categories: system rehabilitation, system expansion, and system enhancement. See detailed notes in:
https://www.fhwa.dot.gov/policy/2010cpr/chap6.cfm#3)

Table 3: Value of minimum revenue guarantee for toll road example ($ millions)

	A. Floor revenue = $15 million				B. Floor revenue = $30 million			
	With risk adjustment		No risk adjustment		With risk adjustment		No risk adjustment	
Guarantee duration	*Declining vol*	*Constant vol*	*Declining vol*	*Constant vol*	*Declining vol*	*Constant vol*	*Declining vol*	*Constant vol*
5	12.8	5.3	10.2	3.5	46.9	31.0	40.0	23.5
10	15.7	13.2	11.7	8.4	67.4	64.8	51.8	47.6
20	26.3	40.5	15.6	25.6	121.4	152.1	78.9	109.7

Notes:

This table reports the minimum revenue guarantee (MRG) values obtained by applying **Equation (4)** for two different floor revenue levels ($15 million and $30 million).

The calculation sequence is as follows:

1. Calculate Revenue Forward Prices (*fw = revenues*exp(rf*time)/(1+ra)^time* ; where rf = risk free rate; ra= real fair value discount rate)
2. Calculate *d1 = (log(fw/strike) + time*(vol1^2)/2) / (vol1*sqrt(time))*
3. Calculate *d2 = d1-(vol1*sqrt(time))*
4. Calculate corresponding cummulative normal distribution values *N(d1)* and *N(d2)*
5. Finally Substitute the above calculated values for *fw, N(d1),* and *N(d2)* in equation for as:

   put = exp(-rf*time)*(strike*N_d2 - fw*N_d1)

In this part of the calculation, we substitute the corresponding floor revenues (i.e. *strike = $15 million* , or *strike = $30 million*) to obtain each component of our table.
By adding up the first {5, 10, 20} put values, we obtain the corresponding value of the minimum revenue guarantees for {5, 10, 20} years duration.
The calculations are made by assuming both: a) flat volatility of 0.3, and b) a declining volatily vector [0.5, 0.5, 0.4, 0.4, 0.3, 0.3, 0.2 thereafter].

Steps 1-5 are then repeated with the only difference that forward price of future revenues is calculated without risk adjustment (i.e. fw = expected future revenue flow).
This will give us the corresponding “No risk adjustment” columns in our table.
The code for these calculations can be followed and replicated in the following electronic notebook:
https://mybinder.org/v2/gh/moshemontesinos/BH_mit_p3_calculator.git/master?urlpath=lab/tree/BH_p3_calculator_v2.ipynb

Table 4: Valuation of Toll Road Project		
($ millions)		
	Risk adjustment, full recognition of subsidy costs	No risk adjustment, no recognition of subsidy costs
Stand-alone NPV	36.7	450.9
Floor revenue guarantee (10 years, $30 million, declining volatility)	-67.4	-51.8
TIFIA guarantees	-22.0	0
muni tax exemption	-39.0	0
positive externalities at 10% of revenues	78.0	145.2
APV	-13.7	544.3

Table 5: Funding models for transportation projects (source: DOT data and authors tabulations)

ALL PROJECTS (= 191 projects)

	PPP	Alternative Project Delivery	Project Finance	TIFIA	Tolling, pricing & Value Capture
TOTAL	47	88	129	78	154
PERCENTAGE	24.6%	46.1%	67.5%	40.8%	80.6%

P3s ONLY (= 47 projects)

	PPP	Alternative Project Delivery	Project Finance	TIFIA	Tolling, pricing & Value Capture
TOTAL	47	8	35	24	39
PERCENTAGE	100.0%	17.0%	74.5%	51.1%	83.0%

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