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Public versus Private Cost of Capital with State-Contingent Terminal Value

Luciano Greco and Mariano Moszoro

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WORKING PAPER

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Public versus Private Cost of Capital with State-Contingent Terminal Value

Prepared by Luciano Greco and Mariano Moszoro*

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ABSTRACT: The economic debate underlines the reasons why discount rates of infrastructure projects should be similar, regardless the public or private source of financing, during the forecast period when flows are risky but predictable. In contrast, we show that the incompleteness of contracts between governments and private firms beyond the forecast period (i.e., when flows of net social benefits are state-contingent) entails expected terminal values that are systematically larger under government rather than private financing. This effect provides a new rationale for applying a lower discount rate in the assessment of projects under public financing as compared to private financing.

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Author's E-Mail Address:	Luciano.greco@unipd.it; Mmoszoro@imf.org

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Prepared by Luciano Greco and Mariano Moszoro[1]

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I. Introduction

Public goods, such as services from public infrastructures and utilities, can be alternatively provided by government or private firms. Though public provision (or *public financing*) involves traditional procurement of inputs over the public investment life cycle from different private firms—e.g., construction and, sometimes, operation services—strategic management, financing, and most of investment and operation risks remain to the public sector. In contrast, with the private provision of public infrastructures and utilities (or *private financing*) the government contracts out within a single public-private partnership (PPP) contract—e.g., to a consortium of private firms—several phases of the investment cycle, including long-run maintenance and most of financing needs and, thus, transfers to the private sector a larger share of investment and operational risks (Engel, Fischer and Galetovic 2014).[1]

The choice of the public sector or private-sector provision of public goods is driven by differentials in capital outlays, operating margins, risk management, and cost of capital. Budget constraints aside, private provision is preferable when a private-sector investor can build the necessary infrastructure cheaper, provide the service at lower operating cost, arrange better financing terms, or combine of these factors that result in higher present value than the public-sector alternative. While there is a consensus on the calculation of investment and operating efficiency—albeit ambiguous empirical results are (Hodge and Greve 2007)—the economics profession is still inconclusive on whether the government financing of a project that generates a stream of net social benefits—i.e., social benefits net of social costs—should imply a lower discount rate than the private financing of the same project.[2]

Boardman and Hellowell (2017) present a survey of discount rates in Value-for-Money (VfM) appraisal practices by PPP agencies. In nine jurisdictions in eight developed countries with government PPP units, four conceptually different types of discount rates are used (see Table 1).[3]

Almost all jurisdictions apply a common discount rate to project flows of net social benefits regardless of the source of financing. Only Australia applies different systematic risk-adjusted discount rates to VfM appraisals, with the public-sector comparator (PSC) rate lower than the PPP rate.

From a normative (welfare economics) point of view, Arrow and Lind (1970), Baumol (1968), Fisher (1973), Samuelson (1964), Solow (1965), and Vickrey (1964) claimed that the discount rate for the public sector should

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[1] Private financing may also involve private ownership of infrastructures, which is typically not the case in civil law countries. Public or private ownership does not affect our analysis and main conclusions.

[2] It is useful to point out that the cost of capital (or discount rate) is specific to the project and, particularly, it is related to the volatility of economic flows (i.e., benefits and costs).

[3] Private investments in toll highways and bridges in the US amounts to billions of dollars. Surprisingly, the US Department of Transportation in its latest guidelines for PPPs devotes only one paragraph to VfM and omits the discussion of discount rates overall (cf. "Successful practices for P3s–A review of what works when delivering transportation via public-private partnerships." Technical report, US Department of Transportation, Federal Highway Administration. March 2016).

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be lower than for the private sector. The public sector can better absorb and spread risks among a greater number of individuals (Arrow and Lind, 1970; Fisher, 1973). Public projects that are complementary to private investments should apply lower discount rates than projects that would replace private investments to partially undo the distortions from other public policies that discourage private investments (Ogura and Yohe, 1977). Private companies' returns come only from the project's cash flows and cannot internalize all the externalities generated by the project; moreover, private investments create externalities that lead to inefficient piece-meal decision-making (Flemming and Mayer, 1997). Thus, the flows of net social benefits of the latter should be discounted at a higher discount rate to avoid this distortion.

Table 1. Discount Rates Used in VfM by PPP Units

Jurisdiction	Discount rate
Australia	PPP vs Public-Sector Comparator (PSC) systematic risk-adjusted rates
Netherlands	PPP's weighted average cost of capital (WACC)
Canada, BC	PPP's weighted average cost of capital (WACC)
Canada, OT	Government borrowing rate
France	Government borrowing rate
Germany	Government borrowing rate
Ireland	Government borrowing rate
South Africa	Government borrowing rate
United Kingdom	Social discount rate

Note: This table presents an overview of the discount rates in Value-for-Money (VfM) appraisal practices in nine jurisdictions in eight developed countries with institutionalized public-private partnership (PPP) programs.

When capital markets are incomplete, investors are unable to hedge themselves against investment risk fully and therefore apply various risk premia. Grout (2003) argued that even in a world with complete markets and no distorting taxation, the differential in the volatility for government payments under private provision is higher than the volatility of government expenditures under public provision and, therefore, it is appropriate to apply a higher discount rate for PPPs compared to public financing. Lind (1990) suggested that the government's long-term borrowing rate is a “good first candidate” for long-run inter-generational analysis and Spackman (2004) stated that “for most government projects we should compute net benefits (from the project) using the government borrowing rate as the discount rate.”

On the other hand, Bailey and Jensen (1972), Brealey, Cooper and Habib (1997), Diamond (1967), Drèze (1974), Hirshleifer (1964; 1966), Kay (1993), and Klein (1997) held that the social discount rate should be higher than the plain public borrowing cost, equaling both public and private discount rates. They argued that the public sector's lower borrowing cost does not reflect more efficient management of risk, but the fact that the public sector does not default and that it can levy taxes to repay debt.

In line with Hirshleifer (1964; 1966), recent research highlights a sound reason to account for market risk premium in the public-sector discount rate–to avoid the distorting incentives of a downwardly biased discount rate. Neglecting the cost of market risk and, thus, deflating the public discount rate would lead to distorted policies, such as: over-investing in risky claims (e.g., student loans; see Lucas, 2012); favoring credit

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assistance instead of economically equivalent benefit payments (Lucas and Phaup, 2008); and twisting the incentives faced by government portfolio managers.[4]

The amount of academic literature supporting the lower cost of capital for the public sector is as vast and robust as that supporting the approach according to which public projects should be discounted at the same rate, irrespective of the source of financing (see, e.g., the discussions in Engel, Fischer and Galetovic, 2013; Grout, 2005, section 2.4; and Green, Koller and Palter, 2015). Writing on the public-sector discount rate, Lind (1982) pointed out that “the profession is no closer to agreement on the theory, on a procedure for computing the discount rate, or on the rate itself than it was in 1966.” This statement still holds: government decision-makers are far from consensus on discount rates used to assess alternative provision modes as well.

Economists and policymakers have a fair understanding of the sources of “red tape” (Bozeman, 1993), differences in public- and private-sector employees’ job perception (Kurland and Egan, 1999; Rainey and Bozeman, 2000) and managerial impact (Meier and O’Toole, 2011), and organizational differences between public, private, and hybrid organizations (Lan and Rainey, 1992; Andrews and Entwistle, 2010). An understanding of corporate financial economics is essential for making investment decisions in the public domain (Coulson, 2008; Lucas, 2012).

In this paper, we contribute to the debate on public versus private discount rates by highlighting a crucial distinction between future flows of the project's net social benefits that are *risky but predictable* as contrasted to future economic flows that are *unpredictable*. For the sake of simplicity but without loss of generality, we focus on a partial equilibrium approach to analyze this issue. Particularly, we abstract from potential general equilibrium effects introduced by investments under consideration or the way the project is funded.

Then, we consider the reasonable assumption that economic flows of the first type materialize within the *forecast period*, while those of the second type unfold beyond the forecast period. A good example of risks that affect economic flows of infrastructure projects in an unpredictable way are linked to alternative climate scenarios. Consider *arguendo* a high-speed railway that is designed to pass through flooding planes. In the long run, such an infrastructure may require climate-change adaptation investments to keep its resilience. The size and design of these investments are contingent on the climate scenario that drives extreme events such as floods and rainfalls.

The discounted sum of unpredictable economic flows—i.e., until the project's actual termination (potentially, indefinite in time) —is the *terminal value* of the forecast period. For example, a financial model may contain predictable economic flows for the operating years 1-10 (i.e., the forecast period), but operations usually endure longer. Years 11 and beyond would generally be presented as the accrued value of these terminal

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[4] For example, when government portfolio managers apply a low discount rate, financial assets in competitive markets appear to be underpriced, thus seemingly making money for the government at purchase and losing money at their sale (CBO, 2003).

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economic flows in year 10, estimated using the dividend discount model (Gordon and Shapiro, 1956; Gordon, 1959): $TV = \frac{A}{r-y}$ is the terminal value, where A are average terminal economic flows, r is the discount rate, and y is the annual growth rate of terminal economic flows in perpetuity. The TV is not a trivial component of valuation. It accounts for around 40-70 percent of the present value of the asset, depending on the size of predictable economic flows, the duration of the forecast period, and the discount rate.[5]

While predictability affords the possibility of writing and implementing (sufficiently) *complete contracts* between private firms and governments during the forecast period, what happens beyond the forecast period cannot, by definition, be contractible. Though we observe clauses about terminal values in public-private contracts, the unpredictability of risks that materializes beyond (or towards) the end of the forecast period implies that the true terminal value is state contingent. In the real world, government and private firms react to unpredictable contingencies. In our previous example, as the climate scenario points towards more frequent floods and rainfalls, new investments can be designed and implemented to adapt (or even fully revamp) the high-speed railway. However, the government and private firms cannot write *ex-ante* credible, binding contracts dealing with such unpredictable contingencies and state-contingent investments.[6] Because of contract incompleteness beyond the forecast period, the strategic interaction between the government and the private firm brings to a systematically larger expected terminal value for publicly financed utilities than for privately financed ones, unless we assume that government is very inefficient in its reaction to new contingencies because of economic failures (e.g., lack of innovation management skills or, simply, tax-and-subsidy distortions) or political failures (e.g., corruption and lobbying). In turn, this provides a new and sound argument in favor of a lower discount rate to assess infrastructure projects that are publicly financed (as opposed to PPPs).

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[5] The following stylized numerical example illustrates this point: Let us assume a series of $100 annuities in perpetuity (A) discounted at a rate (r) of 10 percent annually. The first ten years (n) account for 61 percent of the present value, while the terminal value–i.e., the cash flows from year 11 onwards–for 39 percent of the present value. The shorter the period accounted for the foreseeable cash flows, the lower the discount rate, and the higher the terminal value cash flows growth in perpetuity are, the higher the proportion the terminal value will have in the present value. For $n = 5$ and $r = 7$ percent, the terminal value represents 71 percent of the present value. Putting one's money where the real world is, in 2016 Credit Suisse valued Vinci–the market leader in French toll road concessions–at €77 a share, of which €26.07 (33.8 percent) came from discounted dividends in the next 15 years (2016-2030) and €50.96 (66.2 percent) from the discounted terminal value realized after 2030 (cf. Credit Suisse, "French Infrastructure–Driving Towards Value Creation," October 13, 2016).

[6] This situation can be also interpreted in terms of *state-contingent regulation*, whereas the government does not passively contemplate tail contingencies as they materialize, but reactively adapt the regulation of utilities to face them (Demsetz, 1968; Peltzman, 1976). Inasmuch as future contingencies are unpredictable, unforeseen changes in regulation correspond (by definition) to the terminal value's period (or else, proper economic flows should be predicted and incorporated in the forecast period).

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II. A Financial Model of Infrastructure Projects

Infrastructure projects for the provision of public services (e.g., water and sewage, public transportation, electric grids, and power plants) involve long-term financing and funding. Financing responds to who disburses the investment outlays up front to design and build the infrastructure; it can be the government (e.g., through state-owned enterprises) or a private firm (through a variety of debt and equity instruments). Funding responds to who pays the bills during the operating period; it can also be public—e.g., through subsidies, availability payments, or shadow tolls—or private through user fees. In this paper, we focus on a project that is funded in the same way (e.g., by a mix of public subsidies and tolls), but it can be financed either by the government or the private sector, in a private financing framework. Particularly, we aim at analyzing the cost of capital (or discount rate) that has to be used to assess such a project, depending on whether its financing is public or private.[7]

The methodologies commonly used by policymakers to analyze whether an investment project should be carried on—e.g., cost-benefit analysis—and, further, whether a private provision proposal offers VfM in comparison with the most efficient form of public provision rely on expected (but volatile) economic flows and estimated discount rates. Abstracting from efficiency differentials in investment and operation between the government and the private sector, discount rates drive present value calculations and, therefore, the preference of either public-sector or private-sector provision of public services.

From a financial point of view, the feasibility of an infrastructure project is usually analyzed by deconstructing the future into two parts: a number of periods of *volatile but predictable* flows of net social benefits; and, for the remaining part of the life of the project, *unpredictable* flows of net social benefits that determine the *terminal value* of the project. The total present value of the project is then obtained by adding the discounted value of these two components. Consequently, we can represent the cycle of investment in a public infrastructure as a three-stage process:

(1) At $t = 0$, $I_i > 0$ is invested with certainty by the government—i.e., $i = g$—or the private firm—i.e., $i = p$;
(2) Within the forecast period—i.e., for $t \in (0, n]$, risky but predictable flows of net (expected) social benefits A_{it} are realized, with $i \in \{g, p\}$;
(3) Beyond the forecast period—i.e., for $t \in (n, \infty)$, *Knightian uncertainty* plays in and unpredictable flows of net social benefits are realized; the latter have an expected discounted value at time t_n of $E(TV_i)$, with with $i \in \{g, p\}$.

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[7] To avoid endogeneity and divergence of incentives under public or private financing, we take the point of view of a passive (or minority) shareholder in a publicly or privately financed project. The minority shareholder has no managerial power, the company businesses are identical in terms of construction, access, and demand risks, and the only difference consists of public versus private ownership of the majority stockholding. In the following of the paper, we refer to (public or private) financing or provision interchangeably.

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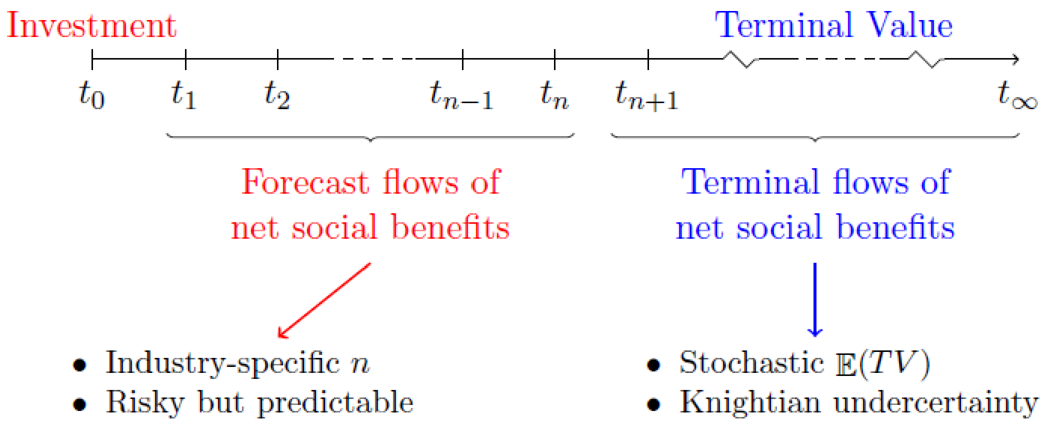
Figure 1 presents the timeline and basic assumptions of the simple financial model of an investment in public infrastructure.

Figure 1. The Cycle of Investment in a Public Infrastructure



The flows of net social benefits at time $t \in (0, \infty)$—i.e., within the forecast period and beyond it—with $i \in \{p, g\}$—i.e., private or government financing—can be decomposed as follows:

$$A_{it} = CS_{it} + PS_{it} \tag{1}$$

where CS_{it} is the consumer surplus and PS_{it} is the producer surplus. Depending on the regulation of the public utility, the producer surplus can be written as:

$$PS_{it} = \tau_{it} A_{it} \tag{2}$$

where $\tau_{it} \in (0,1)$ is the share of net social benefit that corresponds to the cash flows of (private or public) firm that operates the project.[8] Thus, the consumer surplus is:

$$CS_{it} = (1 - \tau_{it}) A_{it} \tag{3}$$

For the sake of simplicity, we assume that flows of net social benefits and the ratio between consumer and producer surplus in the forecast period are time invariant—i.e., $A_{it} = A_i$ and $\tau_{it} = \tau_i$—for all $t \in (0, \infty)$ with $i \in \{p, g\}$. Therefore, the net present value of the infrastructure project is:

---

[8] We assume that $\tau_{it} < 1$ to avoid that the total net social benefit A_{it} coincides with the producer surplus (which is the case when $\tau_{it} = 1$). All the results that follow can be obtained in a more complex and realistic model in which the net social benefit A_{it} reacts to τ_{it}—i.e., where the demand of the public service is elastic to price.

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$$NPV_i = -I_i + \int_0^n A_i e^{-r_i t} dt + E(TV_i) e^{-r_i n} \tag{4}$$

where r_i is the discount rate, $i = g$ if the project is financed by the government, and $i = p$ if the project is financed by the private firm. Therefore, private financing is socially optimal if

$$-I_p + A_p \frac{1-e^{-r_p n}}{r_p} + E(TV_p) e^{-r_p n} > -I_g + A_g \frac{1-e^{-r_g n}}{r_g} + E(TV_g) e^{-r_g n}. \tag{5}$$

When the expected terminal values for the privately and publicly financed projects are equal—i.e., $E(TV_p) = E(TV_g)$—considering that the project's flows of net benefits are risky and predictable during the forecast period, their variance is, by definition, independent of the source of financing. In turn, the two alternative projects can be assessed using the same discount rate, i.e., $r_p = r_g = r$ (Lucas and Phaup, 2008; Lucas, 2012). Therefore, equation (5) simplifies to:

$$I_g - I_p + (A_p - A_g) \frac{1-e^{-rn}}{r} > 0, \tag{6}$$

where $I_g - I_p$ represents the private sector's higher investment efficiency, and $A_p - A_g$ captures the private sector's higher operating efficiency. Investment efficiency is the ability to develop infrastructure of a given quality at lower outlays; operating efficiency refers to the ability to generate higher operating margins through higher revenues and lower operating costs (Bruggink, 1982). Investment and operating efficiency differentials are country- and industry-specific. Private provision may involve an inter-temporal trade-off: higher upfront investment for higher operating efficiency (Hart, Shleifer and Vishny, 1997; Iossa and Martimort, 2012). Equation (6) presents the simple—but deficient—model that is commonly used to assess the VfM of an infrastructure project under private financing versus the same project under public financing. Sophistications with randomization of variables and Monte Carlo analysis can help with risk management but lead to analogous conclusions than the plain model.

If the lifespan of the project is close to the forecast period—e.g., in a finite-life infrastructure project with no terminal value (Blanc-Brude and Hasan, 2015)[9]—the problem is reduced to a managerial exercise contemplated in equation (6) —i.e., the project should be assigned to the party that can achieve overall better investment and operating efficiency. Absent such investment and operation efficiency margins—i.e., if $I_g = I_p$ and $A_p = A_g$—the VfM from private (as compared to public) financing is equal to zero.

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[9] This is the case of the Atlas Arteria road. See: "Atlas Arteria's road to growth" by Graham Witcomb, *Intelligent Investor*, July 23, 2019. Available at: https://www.intelligentinvestor.com.au/recommendations/atlas-arterias-road-to-growth/145907 (accessed April 2022).

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III. A Theory of Endogenous Expected Terminal Value

When the project's lifespan extends beyond the forecast period, the terminal value becomes of key importance for project feasibility. As argued in the Introduction, the terminal value tends to account for a large share of the present value.

The terminal value—which hides most of the *unknowns*—is in itself a discount of expected flows of net social benefits from time $t = n$ onwards. However, beyond the forecast period the flows of net social benefits are risky and unpredictable. Therefore, hedging against such risks relies upon state-contingent investments that can be designed and implemented only after unpredictable events are realized—i.e., after the state of the world is observable.[10] In turn, such risks—that are linked to unpredictable contingencies—cannot be *ex-ante* insured nor *ex-ante* shared between the government and the private firm through an enforceable (private financing) contract. In other terms, beyond the forecast period, contracts between the government and the private partner are *incomplete*.

We rely on a simple model to analyze the effect of contract incompleteness beyond the forecast period on the expected terminal value of public projects. Particularly, we represent the unpredictable risk by assuming that beyond the forecast period the net social benefit can take only two values—e.g., in the example of the high-speed railway, we face two very different climate scenarios—with a Bernoulli's distribution:

B: with probability $\pi \in [0,1]$, the state of the world is “bad,” such that a state-contingent investment (or revamping effort) is needed to hedge against an adverse event that squeezes the flows of net social benefits, i.e., $A_{it} = A_{TV} - [L - h(E)]$, for all $t \in (n, \infty)$, where $h(0) = 0$, $h' > 0$, $h'' < 0$, and $lim_{E \to \infty} h(E) = L > 0$;

G: with probability $1 - \pi$, the state of the world is “good,” such that to keep the long-term flows of net social benefits no state-contingent investment is needed, i.e., $A_{it} = A_{TV}$, for all $t \in (n, \infty)$.

For simplicity, we abstract from any long-term efficiency gap in private versus public operation of the public utility. Thus, A_{TV} is the same for public and private financing, and consistently we assume that $\tau_{it} = \tau$ for for

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[10] We may consider a wide range of activities that can be implemented to hedge against such risks such as *ad hoc* transfers, changes in regulation, and project extensions.

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any $i \in \{p, g\}$.[11] Moreover, $L - h(E)$ is the average loss in long-run net social benefits that materializes in the state of the world B and can be mitigated by a revamping effort or investment, $E \geq 0$, implemented by the private firm or the government, depending on the financing structure.[12] Again, to keep the formalization minimal, we assume that the cost of the revamping effort fully accrues just after the forecast period—i.e., at time n.[13] The state of the world—i.e., G or B—is *ex post* observable but not *ex ante* contractible. Therefore, the level of E depends on the financing framework of the public utility.

A. Public Financing

In the case of public financing, the government can rely on the public governance to enforce the desired level of E, after the state of the world is observed. This is the case when a public project is implemented and operated by a governmental agency or publicly owned firm. In our analysis, we first assume away any source of potential inefficiency (e.g., transaction costs, agency problems) that the government may face in reacting to new contingencies (Section 3.1.1); then, we analyze the case in which government is less efficient than private firms in implementing the revamping effort (Section 3.2.1).

A.1 Efficient Government

If the government faces the same costs as a private firm in implementing a given revamping effort, in the state of the world

B: the government maximizes the discounted net social benefit, including the cost of revamping effort,

$$\underline{W}(E) = \int_0^\infty [A_{TV} - (L - h(E))]e^{-rt}dt - E = \frac{A_{TV} - (L - h(E))}{r} - E; \tag{7}$$

G: no revamping effort is needed to support the long-run level of net social benefits—i.e., $E = 0$—thus the government obtains the discounted net social benefit,

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[11] While the literature across a variety of industries has found that there are differences in operating efficiency—e.g., private-sector innovation and cost reduction (Chopra, 2014)—there is no theoretical rationale nor empirical evidence to assume a *perpetual* private-sector operating efficiency advantage (Meier and O'Toole, 2011). For example, Jeong, Moon and Bae (2017) found that the solid waste service costs were lower under contracting-out than under direct public delivery only in about half of the cases and Le Lannier and Porcher (2014) found that after taking the environmental variables into account, French water supply companies under private management are on average slightly less efficient than public management. Thus, repeated interactions between firms and the government, personnel flows, and technology transfers suggest that, holding the project characteristics constant, the efficiency of public and private operators should converge over time.

[12] For example, the Multi-Hazard Mitigation Council (2019) roughly calculated that retrofitting and upgrading telecommunications, roads, power, and water utilities in the US to better resist disasters could save US$4 per US$1 of revamping investment.

[13] Our results hold also in a framework in which such a cost materializes over several periods. Particularly, mitigation investments can be implemented also before the end of the forecast period. For example, using 12 grants from the Economic Development Administration (EDA) as case studies, the Multi-Hazard Mitigation Council (2019) estimated benefit-cost ratios (BCRs) between 2.0 and 11.0 in four grants in flood mitigation for roads and railroads (and one grant exhibiting a BCR of 0.2), between 1.3 and 31.0 in four grants flood mitigation for water and wastewater facilities, ca. 8.5 in two grants in wind mitigation for electric and telecommunications, and 9.4 in one grant in flood mitigation for electric and telecommunications. That is why our theory of endogenous expected terminal value of public projects applies to PPPs, such as Build-Operate-Transfer (BOT) schemes, as well as to privately operated utilities.

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$$\overline{W} = \int_0^\infty A_{TV}\, e^{-rt} dt - E = \frac{A_{TV}}{r}. \tag{8}$$

In the state of the world B, the government determines the optimal state-contingent investment to maximize $\underline{W}(E)$. By the first order condition of the objective function (7) with respect to E, we obtain the optimization condition:

$$\frac{h'(E_g)}{r} = 1, \tag{9}$$

where E_g is the optimal public investment in the bad state of the world. Therefore, we can calculate the expected terminal value, considering the government state-contingent revamping effort:

$$E(TV_g) = \pi \underline{W}(E_g) + (1-\pi)\overline{W} = \frac{A_{TV}}{r} - \pi\left(\frac{L - h(E_g)}{r} + E_g\right). \tag{10}$$

A.2 Inefficient Public Revamping

Let now us consider the case in which the government faces additional costs in implementing the revamping effort. These additional costs may derive by several political and economic failures of governments, such as: political agency and transaction costs in the relationship with the entity or publicly owned firm that operates the public project, tax, and subsidy distortions, or—more properly—the comparative disadvantage with respect to the private sector in designing and implementing innovations that are required by unpredictable events. Particularly, we assume that, in the state of the world B, the government maximizes

$$\underline{\widehat{W}}(E) = \frac{A_{TV} - (L - h(E))}{r} - E(1+\delta), \tag{11}$$

where $\delta \geq 0$ represents the additional *marginal cost of public revamping* that government faces to implement E, compared to a private firm. Let us also remark that the problem (11) boils down to (7) when $\delta = 0$.

Of course, in this case, the government's optimal revamping effort is smaller, i.e.:

$$\frac{h'(E_g)}{r} = 1 + \delta; \tag{12}$$

thus, the expected terminal value is:

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$$E(\widehat{TV}_g) = \pi \underline{\widehat{W}}(\hat{E}_g) + (1-\pi)\overline{W} = \frac{A_{TV}}{r} - \pi\left[\frac{L - h(\hat{E}_g)}{r} + \hat{E}_g(1+\delta)\right]; \tag{13}$$

and, we have the following result:

Proposition 1 *Under public financing, the expected terminal value of public projects is decreasing in the marginal cost of public revamping*.

Proof By the Envelope Theorem, $\frac{\partial}{\partial\delta}\underline{\widehat{W}}(\hat{E}_g) = -\hat{E}_g$, hence $\frac{\partial}{\partial\delta}E(\widehat{TV}_g) = -\pi\,\hat{E}_g < 0$.

This result is quite intuitive: as the government becomes less efficient in implementing state-contingent revamping efforts, the expected terminal value of the public project drops, because of insufficient revamping effort.

B. Private Financing

In case of private financing, the government and the private firm cannot contract ex ante on E. The government maximizes the net social welfare, including possible government subsidies to the private firm. Particularly, this is given by the expressions (7) and (8) minus λS, where $\lambda > 0$ is the marginal cost of public funds and S is the government subsidy to the private firm.[14] The private firm maximizes the producer surplus, including possible government subsidy. Thus, in the state of the world

B: the private firm maximizes the discounted producer surplus that includes the cost of revamping effort and the government's subsidy,

$$\underline{PS}(E) + S = \int_0^\infty \tau[A_{TV} - (L - h(E))]e^{-rt}dt - E + S = \tau\frac{A_{TV} - (L - h(E))}{r} - E + S; \tag{14}$$

G: no revamping effort (hence, no subsidy) is optimal nor implemented in the good state of the world—i.e., $E = S = 0$—thus, the private firm obtains the discounted producer surplus,

$$\overline{PS} + S = \int_0^\infty \tau A_{TV}\, e^{-rt}dt - E + S = \tau\frac{A_{TV}}{r}. \tag{15}$$

---

[14] Following Engel, Fischer and Galetovic (2013), we introduce an exogenous marginal cost of public funds. All our results can also be obtained in a more general model featuring a demand for the public service that decreases in τ; in such a model, instead of paying a subsidy, the government could implement the same result by increasing τ to compensate the private firm for the larger investment in E.

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It is important to remark that, once the state of the world is realized, the *ex-post verifiability* of E becomes important to determine the expected terminal value of the public project. In the following, we consider the two polar cases:

1. E can only be observed by both parties (i.e., the government and the private firm), but it is *ex post* unverifiable;[15]
2. E is also *ex-post* verifiable.

B.1 Unverifiable State-Contingent Investment

Because E is not verifiable, contracts are incomplete also after the state of the world B is observed by both parties. Therefore, the government cannot provide any subsidy to incentivize the private firm to implement a given level of E—thus $S = 0$. Since the project is privately financed, at the time n the firm maximizes the objective function (14) with respect to E. By the first order condition of the private firm's problem, we obtain the optimization condition:

$$\tau \frac{h'(E_p)}{r} = 1; \tag{16}$$

where E_p is the optimal private investment under unverifiable revamping effort. Therefore, we can calculate the expected terminal value substituting in the expression (10) the state-contingent effort that is decided by the private firm:

$$E(TV_p) = \pi \underline{W}(E_p) + (1-\pi)\overline{W} = \frac{A_{TV}}{r} - \pi\left(\frac{L - h(E_p)}{r} + E_p\right). \tag{17}$$

Thus, we have the following result:

Proposition 2 *When state-contingent revamping efforts beyond the forecast period are ex-post unverifiable, the expected terminal value of public projects under public financing is always larger than under private financing*.

Proof Given that $\tau < 1$, by the comparison of the expressions (9) and (16), it follows that $E_g > E_p$, hence $\underline{W}(E_g) > \underline{W}(E_p)$, which implies that $E(TV_g) > E(TV_p)$.

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[15] Transformative innovations change observable stage-contingent investments over time whose ultimate efficacy may not be verifiable over a long period. For example, 3D printing is poised to totally disrupt construction sites, new products like CLT (cross-laminated timber, formed by stacking and gluing perpendicular layers of wood) and Glulam (glue-laminated timber, formed by stacking and gluing layers of wood directly on top of each other) are allowing for higher and stronger wood buildings, and lightweight, prefabricated, modular roads are made with recycled plastic waste. See: "6 innovative technologies about to transform our infrastructure" by Joseph Losavio, *World Economic Forum*, September 17, 2019. Available at: https://www.weforum.org/agenda/2019/09/6-revolutionary-techniques-about-to-transform-our-infrastructure/ (accessed May 2022).

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The intuition of this result is straightforward. Under private financing, the firm is able to reap only a fraction of the (social) positive effect of the (unverifiable) revamping investment on the terminal value, therefore it under-invests compared to the public financing case. Moreover, the government and the private firm cannot *ex-post* negotiate to correct such a situation, given that the revamping effort is also unverifiable. The result of Proposition 2 crucially depends on the assumption that $\tau < 1$, i.e., that the producer's surplus does not exhaust the social welfare. Conversely, if $\tau = 1$ the net social benefits coincide with the producer's surplus, and the externality that generates the result of Proposition 2 disappears, thus $E_g = E_p$. As argued above, the assumption that $\tau < 1$ is a shortcut to represent a more realistic model in which the demand for the public service decreases as its price increases, or—in our model's terms—the flow of net social benefit decreases as τ increases.

Two additional remarks are in order here. First, in the real-world state-contingent investments that affect the terminal value may be implemented also before the forecasted timespan of the project and not necessarily after it as soon as the state of the world unfolds. Second, and related to the first consideration, the reason why private financing leads to insufficient state-contingent investments is relevant also for Build-Operate-Transfer (BOT) PPPs, as far as not all determinants of the terminal value can be *ex ante* contracted on.

B.2 Verifiable State-Contingent Investment

In this case, the government and the private firm can negotiate on the state-contingent investment and on a government subsidy, after they observe that the state of the world is B. The negotiation has to satisfy the *participation constraints* of both parties. In case of disagreement, the private firm would choose E_p, obtaining a payoff equal to $\underline{PS}(E_p)$; and the government would obtain a payoff equal to $\underline{W}(E_p)$. Therefore, the government is interested in negotiating a different level of E if:

$$\underline{W}(E) - \lambda S \geq \underline{W}(E_p) \tag{18}$$

Similarly, the private firm is interested in participating in the negotiation over E only if:

$$\underline{PS}(E) + S \geq \underline{PS}(E_p) \tag{19}$$

By the participation constraint of the private firm, we have the following result:

Proposition 3 *The minimum subsidy that the government has to pay to the private firm in the framework of a negotiation in the bad state of the world,* $\underline{S}$*, is strictly positive whenever* $E \neq E_p$*.*

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Proof By the constraint (19), any feasible negotiation is such that $S \geq \underline{S} \equiv \underline{PS}(E_p) - \underline{PS}(E)$. By the optimization condition (16), $E_p = \underset{E}{argmax}\, \underline{PS}(E)$, thus $\underline{PS}(E_p) - \underline{PS}(E) \geq 0$ for all possible E and, particularly, it is equal to zero only if $E \neq E_p$.

As usual in the economic literature, we represent this negotiation by the solution to a Nash bargaining problem (Binmore, Rubinstein and Wolinsky, 1986; Van Damme, 1986) —i.e., by the maximization of the Nash product:

$$\left(\underline{W}(E_p^b) - \lambda S - \underline{W}(E_p)\right)^{\gamma} \left(\underline{PS}(E_p^b) + S - \underline{PS}(E_p)\right)^{1-\gamma}, \tag{20}$$

where γ is the bargaining power of the government and $1 - \gamma$ is the bargaining power of the private firm. Thus, at the time n, the government and the firm jointly maximize the Nash product (20) with respect to E_p^b and S. By the first order conditions of such a cooperative maximization problem, we obtain the optimization condition:

$$\frac{h'(E_p^b)}{r} = \frac{2}{1+\tau} \tag{21}$$

that characterizes the optimal revamping effort that is negotiated by the government and the private firm.[16]

Therefore,

$$E(TV_p^b) = \pi\left(\underline{W}(E_p^b) - \lambda S^b\right) + (1-\pi)\overline{W} = \frac{A_{TV}}{r} - \pi\left(\frac{L - h(E_p^b)}{r} + E_p^b + \lambda\, S^b\right). \tag{22}$$

Thus, we have the following results:

Proposition 4 *When state-contingent revamping efforts beyond the forecast period are ex-post verifiable, the expected terminal value of public projects under public financing is always larger than under private financing.*

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[16] The condition (21) is obtained by substituting the first order condition of the maximization of (20), that can also be written as:

$$\left(\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p - \lambda S\right)^{\gamma} \left(\tau\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p + S\right)^{1-\gamma},$$

with respect to E_p^b,

$$\gamma\frac{\frac{h\prime(E_p^b)}{r} - 1}{\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p - \lambda S} + (1-\gamma)\frac{\tau\frac{h\prime(E_p^b)}{r} - 1}{\tau\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p + S} = 0,$$

in the first order condition with respect to S,

$$-\gamma\frac{1}{\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p - \lambda S} + (1-\gamma)\frac{1}{\tau\frac{h(E_p^b)-h(E_p)}{r} - E_p^b + E_p + S} = 0.$$

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Proof Given that $\tau < 1$, by the comparison of the expressions (9) and (21), it follows that $E_g > E_p^b$, hence $\underline{W}(E_g) > \underline{W}(E_p^b)$ and, *a fortiori*, $\underline{W}(E_g) > \underline{W}(E_p^b) - \lambda S^b$. The latter expression implies that $E(TV_g) > E(TV_p^b)$.

Proposition 4 shows that the possibility to verify revamping investments, and thus negotiate *ex post* on them, does not remove the fundamental problem of private financing (as compared to public financing) that arises by the lack of full internalization of the positive effects of such efforts on the terminal value. The following result provides us with a (rather intuitive) ranking, in terms of social welfare, between the two situations.

Proposition 5 *The expected terminal value of privately financed public projects is larger (or at least equal) under ex-post verifiability of state-contingent revamping effort than under ex-post unverifiability of it*.

Proof By the participation constraint of the government (18), the optimal solution of the problem (20) is such that $\underline{W}(E_p^b) - \lambda S^b \geq \underline{W}(E_p)$, therefore $E(TV_p^b) \geq E(TV_p)$.

The intuition of Proposition 5 is, again, straightforward. When the effort that improves the terminal value of the project is *ex-post* verifiable, the government and the private firm may forge an agreement—e.g., a given level of subsidy in exchange for a given level of investment—that improves their payoffs. This possibility implies that the positive impact on the terminal value is larger (or at least equal) than in the case of unverifiable state-contingent revamping efforts.

B.3 Public Versus Private Financing When Public Revamping is Inefficient

Propositions 2 and 4 hold under the assumption that government is as efficient as the private sector in revamping the private project after a new contingency materializes (e.g., climate-change adaptation investments are necessary). While it is sound to consider that economic flows (both within and beyond the forecast period) cannot systematically differ across public and private sectors, revamping innovations may reasonably be more efficiently (e.g., earlier, at lower costs) adopted by private firms.

Let us compare a government that faces a marginal cost of public revamping (as in Section 3.1.2) with the outcome of private financing under unverifiable revamping effort. By the optimization conditions (12) and (16), we first observe that $\hat{E}_g > E_p$ if and only if $\delta < \frac{1-\tau}{\tau}$. The following proposition characterizes, in particular, the trade-off between efficiency gains and losses of public financing in the more general setting under consideration:

Proposition 6 *When state-contingent revamping efforts beyond the forecast period are ex-post unverifiable, the expected terminal value of public projects under public financing is larger (smaller) than under private financing if and only if* $\delta < \overline{\delta} < \frac{1-\tau}{\tau}$ *(*$\delta > \overline{\delta}$*).*

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Proof The difference between the (optimal) expected terminal values under public financing (with inefficient public revamping) and private financing (with unverifiable revamping effort) is strictly positive if and only if:

$$\frac{h(\hat{E}_g)}{r} - \hat{E}_g(1+\delta) > \frac{h(E_p)}{r} - E_p \tag{23}$$

By the second-order Taylor approximation of the expression $\frac{h(\hat{E}_g)}{r} - \hat{E}_g$ around $\frac{h(E_p)}{r} - E_p$, the condition (23) is equivalent to $\delta < \overline{\delta}$, where

$$\overline{\delta} \equiv \frac{1-\tau}{\tau} - \frac{1-\tau}{\tau}\frac{E_p}{\hat{E}_g} + \frac{h''(E_p)}{2r}\frac{\left(\hat{E}_g - E_p\right)^2}{\hat{E}_g} < \frac{1-\tau}{\tau}$$

The intuitive interpretation of this result is that when government is very inefficient at implementing revamping, it also determines a lower expected terminal value, compared to the private financing. Two considerations are in order here. First, for relatively small marginal cost of public revamping δ, all our previous results hold. Second, for very inefficient government revamping (i.e., $\delta > \overline{\delta}$), the expected terminal value of public financing is smaller than private financing which would bring to a larger discount rate for public financing in contrast to private financing.

Similar results can be obtained also in the case of private financing with ex post verifiable revamping efforts, though the threshold on the marginal cost of public revamping is different and, particularly, depends on the size of the subsidy from government to the private firm, which in turn relies on the relative bargaining power of government γ. Particularly, a government with smaller bargaining power would negotiate larger subsidies to implement revamping (under private financing). The latter effect would drive up E_p^b, thus decreasing the threshold on δ below which public financing brings to larger expected terminal values.

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Equation (6), then, can be re-expressed as:

$$I_g - I_p + (A_p - A_g)\frac{1-e^{-rn}}{r} > \left[E\left(TV_g\right) - E\left(TV_p\right)\right]e^{-rn} > 0. \tag{24}$$

Because there is no way to adjust cash flows for Knightian uncertainty, a blunt across-the-board adjustment should be applied in the discount rate. If the public revamping is not too inefficient, $E(TV_g) > E(TV_p)$, hence the discount rate of publicly financed projects should be lower than the discount rate of privately financed projects–

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–i.e., $r_g < r_p$. *A contrario*, should investment efficiency, operating efficiency, and expected returns be equal, no investor would invest in a private project with lower terminal value (Sharpe, 1964).

In real-world projects, the main rationale for comparing traditional procurement of public projects with PPPs is that public or private financing typically entail different degrees of investment and operation efficiency. Our argument in favor of a lower discount rate for government financing implies that, whenever the private sector is *more* efficient than the public sector (e.g., because of better management or enhanced attitude towards innovation), a trade-off arises between such efficiency gains and the lower cost of capital that government faces because of larger expected terminal values.

IV. Conclusion

There has been a long-standing dispute about the relative costs of public versus private finance. Many studies, including the influential paper by Arrow and Lind (1970), have suggested that the public costs are lower, providing different reasonings for this belief. On the other side of the discussion, Hirshleifer (1964) and several recent authors (Lucas, 2012; Engel, Fischer and Galetovic 2013) have argued that the argument is incorrect because, in efficient markets, investors can diversify risks on their own, a downwardly biased public discount rate can provide distorted incentives to the government, and governments can ultimately increase taxation to subsidize projects. Thus, even though the cost of government finance may be lower, the overall cost of capital to the ultimate principal—i.e., the public—could well be higher.

Due to long investment cycle periods, low number of comparable projects, and—foremost—unavailable continuous market pricing or net benefit-flow performance of public-sector utilities, the question of the proper discount rate for publicly versus privately financed infrastructure projects remains normative. The kernel of the conundrum lies in the treatment of tail risks—low-probability, extreme-impact outcomes embedded in the terminal value—which differ between the public and private sectors due to the discretionary and asymmetric response of governments and private firms to unknown events.

The implications of the study hitherto are twofold. A lower public than private discount rate ($r_g < r_p$) should be applied to the feasibility analysis of provision modes in public infrastructures and utilities (in line with Arrow and Lind, 1970; Peltzman, 1976; and Grout, 2003). Consequently, the efficiency gains in investment—i.e., $I_g - I_p$—and operations—i.e., $A_p - A_g$—from private provision must be higher than commonly accepted to deliver a greater value for money in comparison to public provision to compensate for the lower expected terminal value—i.e., $E(TV_g) > E(TV_p)$.

Our contribution is very relevant for cost-benefit analysis of public projects under climate change. In the last decades, several works have made the case for a *decreasing discount rate* in cost-benefit analysis of projects dealing with far-distant—hence, very uncertain or misperceived by policymakers—future economic flows—

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e.g., Weitzman (1998), Arrow et al. (2013), and Karp (2005). Our argument—that relies on the *ex-post* endogeneity of future economic flows thanks to revamping efforts—holds also in settings with decreasing (or, more generally, time-varying) discount rates and, thus, is complementary to these arguments.

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References

Andrews, R. and T. Entwistle, 2010, "Does Cross-Sectoral Partnership Deliver? An Empirical Exploration of Public Service Effectiveness, Efficiency, and Equity," *Journal of Public Administration Research & Theory*, Vol. 20(3), pp. 679–701.

Arrow, K., M. Cropper, C. Gollier, B. Groom, G. Heal, R. Newell, W. Nordhaus, R. Pindyck, W. Pizer, P. Portney, T. Sterner, R. S. J. Tol, and M. Weitzman, 2013, "Determining benefits and costs for future generations," *Science*, Vol. 341(6144), pp. 349–350.

Arrow, K. J. and R. C. Lind, 1970, "Uncertainty and the evaluation of public investment decisions," *American Economic Review*, Vol. 60(3), pp. 364–378.

Bailey, M. J. and M. C. Jensen, 1972, "Risk and the discount rate for public investment," In M. C. Jensen, Ed.), *Studies in the Theory of Capital Markets*. Praeger Publishers.

Baumol, W. J., 1968, "On the social rate of discount," *American Economic Review*, Vol. 58(4), pp. 788–802.

Binmore, K., A. Rubinstein, and A. Wolinsky, 1986, "The Nash bargaining solution in economic modelling," *RAND Journal of Economics*, Vol. 17(2), pp. 176–188.

Blanc-Brude, F. and M. Hasan, 2015, "The valuation of privately-held infrastructure equity investments," Technical report, EDHEC-Risk Institute.

Boardman, A. E. and M. Hellowell, 2017, "Comparison and analysis of specialist PPP units' methodologies for conducting value for money analysis," *Journal of Comparative Policy Analysis*, Vol. 19(3), pp. 191–206.

Bozeman, B., 1993, "A theory of government 'red tape'," *Journal of Public Administration Research & Theory*, Vol. 3(3), pp. 273–303.

Brealey, R. A., I. A. Cooper, and M. A. Habib, 1997, "Investment appraisal in the public sector," *Oxford Review of Economic Policy*, Vol. 13(4), pp. 12–28.

Bruggink, T. H., 1982, "Public versus regulated private enterprise in the municipal water industry: a comparison of operating costs," *Quarterly Review of Economics & Business*, Vol. 22, pp. 111–125.

CBO, 2003, "Evaluating and accounting for federal investment in corporate stocks and other private securities," CBO Study, The Congress of the United States, Congressional Budget Office, Washington, DC.

Chopra, A., 2014, *Innovative State: How New Technologies Can Transform Government*. New York, NY: Atlantic Monthly Press.

Coulson, A., 2008, "Value for money in PFI proposals: A commentary on the UK Treasury Guidelines for Public Sector Comparators," *Public Administration*, Vol. 86(2), pp. 483–498.

Demsetz, H., 1968, "Why regulate utilities?" *Journal of Law & Economics*, Vol. 11(1), pp. 55–65.

Diamond, P. A., 1967, "The role of a stock market in a general equilibrium model with technological uncertainty," *American Economic Review*, Vol. 57(4), pp. 759–776.

Drèze, J. H., 1974, "Discount rates and public investment: A post-scriptum," *Economica*, Vol. 41(161), pp. 52–61.

©International Monetary Fund. Not for Redistribution

Engel, E., R. Fischer, and A. Galetovic, 2013, "The Basic Public Finance of Public-Private Partnerships," *Journal of the European Economic Association*, Vol. 11, pp. 83–111.

Engel, E., R. Fischer, and A. Galetovic, 2014, *The Economics of Public-Private Partnerships*. Cambridge University Press.

Fisher, A. C., 1973, "Environmental externalities and the Arrow-Lind public investment theorem," *American Economic Review*, Vol. 63(4), pp. 722–725.

Flemming, J. and C. Mayer, 1997, "The assessment: public-sector investment," *Oxford Review*

of Economic Policy, Vol. 13(4), pp. 1–11.

Gordon, M. J., 1959, "Dividends, earnings and stock prices," *Review of Economics & Statistics*, Vol. 41(2), pp. 99–105.

Gordon, M. J. and E. Shapiro, 1956, "Capital equipment analysis: The required rate of profit," *Management Science*, Vol. 3(1), pp. 102–110.

Green, A., T. Koller, and R. Palter, 2015, "A hidden roadblock in public-infrastructure projects," *Corporate Finance Practice*, McKinsey & Company.

Grout, P. A., 2003, "Public and private sector discount rates in public-private partnerships," *Economic Journal*, Vol. 113(486), pp. C62–C68.

Grout, P. A., 2005, "Value-for-Money measurement in public–private partnerships," *EIB Papers*, Vol. 10(2), pp. 33–56.

Hart, O., A. Shleifer, and R. W. Vishny, 1997, "The proper scope of government: Theory and an application to prisons," *Quarterly Journal of Economics*, Vol. 112(4), pp. 1127–1161.

Hirshleifer, J., 1964, "Efficient allocation of capital in an uncertain world," *American Economic Review*, Vol. 54(3), pp. 77–85.

Hirshleifer, J., 1966, "Investment decision under uncertainty: Applications of the state-preference approach," *Quarterly Journal of Economics*, Vol. 80(2), pp. 252–277.

Hodge, G. A. and C. Greve, 2007, "Public-private partnerships: An international performance review," *Public Administration Review*, Vol. 67(3), pp. 545–558.

Iossa, E. and D. Martimort, 2012, "Risk allocation and the costs and benefits of public–private partnerships," *RAND Journal of Economics*, Vol. 43(3), pp. 442–474.

Jeong, S.-Y., S.-G. Moon, and S. Bae, 2017, "A comparative study of the effects of institutional arrangements in municipal solid waste services in Korea," *Journal of Comparative Policy Analysis*, Vol. 19(1), pp. 17–39.

Karp, L., 2005, "Global warming and hyperbolic discounting," *Journal of Public Economics*, Vol. 89(2-3), pp. 261–282.

Kay, J., 1993, *Efficiency and Private Capital in the Provision of Infrastructure*. Paris: OECD.

Klein, M., 1997, "The risk premium for evaluating public projects," *Oxford Review of Economic Policy*, Vol. 13(4), pp. 29–42.

Kurland, N. B. and T. D. Egan, 1999, "Public v. private perceptions of formalization, outcomes, and justice," *Journal of Public Administration Research & Theory*, Vol. 9(3), pp. 437–458.

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Lan, Z. and H. G. Rainey, 1992, "Goals, rules, and effectiveness in public, private, and hybrid organizations: More evidence on frequent assertions about differences" *Journal of Public Administration Research & Theory*, Vol. 2(1), pp. 5–28.

Le Lannier, A. and S. Porcher, 2014, "Efficiency in the public and private French water utilities: prospects for benchmarking," *Applied Economics*, Vol. 46(5), pp. 556–572.

Lind, R. C., 1982, *Discounting for Time and Risk in Energy Policy, Resources for the Future*. Baltimore: Johns Hopkins University Press.

Lind, R. C., 1990, "Reassessing the government's discount rate policy in light of new theory and data in a world economy with a high degree of capital mobility," *Journal of Environmental Economics & Management*, Vol. 18(2), pp. S8–S28.

Lucas, D., 2012, "Valuation of government policies and projects," *Annual Review of Financial Economics*, Vol. 4(1), pp. 39–58.

Lucas, D. and M. Phaup, 2008, "Reforming credit reform," *Public Budgeting & Finance*, Vol. 28(4), pp. 90–110.

Meier, K. J. and L. J. O'Toole, 2011, "Comparing public and private management: Theoretical expectations," *Journal of Public Administration Research & Theory*, Vol. 21(suppl 3), pp. i283–i299.

Multi-Hazard Mitigation Council, 2019, *Natural Hazard Mitigation Saves: 2019 Report*. Washington, DC: National Institute of Building Sciences.

Ogura, S. and G. Yohe, 1977, "The complementarity of public and private capital and the optimal rate of return to government investment," *Quarterly Journal of Economics*, Vol. 91(4), pp. 651–662.

Peltzman, S., 1976, "Toward a more general theory of regulation," *Journal of Law & Economics*, Vol. 19(2), pp. 211–240.

Rainey, H. G. and B. Bozeman, 2000, "Comparing public and private organizations: Empirical research and the power of the a priori," *Journal of Public Administration Research & Theory*, Vol. 10(2), pp. 447–470.

Samuelson, P. A., 1964, "Principles of efficiency: Discussion," *American Economic Review*, Vol. 54(3), pp. 93–96.

Sharpe, W. F., 1964, "Capital asset prices: A theory of market equilibrium under conditions of risk," *Journal of Finance*, Vol. 19(3), pp. 425–442.

Solow, R. M., 1965, *Capital Theory and the Rate of Return*. Chicago: Rand McNally.

Spackman, M., 2004, "Time discounting and of the cost of capital in government," *Fiscal Studies*, Vol. 25(4), pp. 467–518.

Van Damme, E., 1986, "The Nash bargaining solution is optimal," *Journal of Economic Theory*, Vol. 38(1), pp. 78–100.

Vickrey, W., 1964, "Principles of efficiency: Discussion," *American Economic Review*, Vol. 54(3), pp. 88–92.

Weitzman, M. L., 1998, "Why the far-distant future should be discounted at its lowest possible rate," *Journal of Environmental Economics & Management*, Vol. 36(3), pp. 201–208.

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