THE PROBLEM OF DISCOUNT RATE IN INFRASTRUCTURE PROJECT: EXPLORING THE IDEA OF FINANCIAL TWINS

Ken Fuller[1], Zhen Ye* [1, 2], Tim Broyd[1], Long Chen[3]

*Corresponding author Zhen Ye (Peter), Email: p.ye@ucl.ac.uk

[1] The Bartlett School, University College London, 1-19 Torrington Place, London, UK

[2] The School of Economics, Xiamen University, Fujian, 361005, China

[3] The School of Architecture, Building and Engineering, Loughborough University, UK

ABSTRACT

Investment in infrastructure assets represents allocation of financial resources to long-lived, physical assets. Managing risk to maximize returns and minimize unforeseen negative outcomes is key to increasing investor confidence and the attractiveness of investing in infrastructure. The nature of risk represents unknown future outcomes throughout the asset lifecycle. Though static at a point in time, risk profiles vary temporally, updated constantly by a variety of factors; some factors are controllable by management decisions, while others are subject to broader market forces. The paper examines the alignment of financial modelling practice and the variable-temporal nature of risk, and proposes a digital architecture to improve its monitoring, coined the ‘financial twin’. By improving risk monitoring of assets throughout their lifecycle, infrastructure owners and managers are able increase the asset performance and financial returns through targeted management interventions, increasing asset value and minimizing the impacts of emergent risks, in-line with the practice of asset management.

KEYWORDS: *risk temporality, risk variability, financial twin, asset management*

1. INTRODUCTION

The provision of infrastructure is well documented to be critically important to the needs of society, allowing for the provision of life-critical services and economic growth (Gurara; et al., 2017). Specific definitions of infrastructure can be a subject of debate, but generally include "the underlying framework or foundation of a system", and can, in this context, include transportation, communication, and basic public service systems (Frischmann, 2012). The sector is further defined by being real assets, with long lifespans and investment horizons (Andonov et al., 2021). These last features of the sector become critically important when examining the risk profiles of infrastructure assets – real assets are subject to a broader set of risks, and their long duration provides more opportunity for risks to be realized. Further, it can be observed that the risk profile of infrastructure assets expands beyond strictly financial risks throughout the lifespan of the asset – risks introduced by required maintenance regimes or decommissioning activities will change the risk profile of the asset throughout the lifecycle, causing a risk 'life' beyond the monetary value of the asset.

Risk is inherently a dynamic factor in infrastructure assets. It varies temporally and based on exogenous factors and endogenous aspects such as management decisions (Danielson, 2022; OECD, 2015). The infrastructure sector lacks a consistent definition of risk (Schwartz *et al.*, 2014), but generally accepts some variation on the concept of "the effect of uncertainty on objectives" (British Standards Institution, 2014). This gives rise to the concept of 'probability of an event × the severity of impact' to describe the significance of risk (Amyotte and McCutcheon, 2006; Moteff, 2005). This description has some limitations, but generally applied can provide a quantifiable understanding of a specific risk's impact to an asset.

This paper contributes to academic thought by challenging current, commonplace application of the discount rates as a tool to describe infrastructure risks, highlighting disconnect between the nature of infrastructure risk and practical applications of the discount rate, and proposes a theoretical architecture by which risks can be tracked and used to increase the value of infrastructure investments. The paper will attempt to synthesize the latest industry and academic thought on alignment of the temporal-variable nature of risk as described through what we called the problem of discount rate, specifically to gain understanding of how the infrastructure sector applies discount rates to track risks of assets. Of particular interest is the application of a singular or multiple discount rates to account for the variable nature of risk, and how the temporal nature of risk handled throughout the asset lifecycle.

The paper is organized into six sections. Section 2 starts with a background to define the treatment of risk in the infrastructure sector to problematize the use of discount rate. We argue that a broader understanding of asset risks is needed in practice. Section 3 outlines the methodology used in the reviews of literature conducted and section 4 presents the findings of the reviews. Section 5 is an analysis of the findings and proposes a methodology by which the variable and temporal nature of risk can be incorporated into dynamic financial models in the form of a 'financial twin' of infrastructure assets to improve risk visibility and influence management decisions. Finally, section 6 highlights limitations, and proposes areas of future research in the conclusion.

2. THE PROBLEM OF DISCOUNT RATE

Risk management is defined as an "organization's coordinated activities and methods used to monitor and control the many unplanned events that can affect an organization's ability to achieve its objectives" (British Standards Institution, 2020). Amyotte and McCutcheon (2006) breaks down risk management further, highlighting two perspectives in projects: financial and technical. Financial risks encompass a wide range of factors that can affect the financial viability of an asset. These can include political and regulatory risks, macroeconomic and business risks, sectoral risks, external market volatility risk, contractual risk, and project specific structural risks (Schwartz *et al.*, 2014, OECD, 2015). The long lifecycle of infrastructure assets increases exposure to financial changes over the lifespan of the asset, increasing the number of uncertainties on asset finances into the future. Additionally, factors such as the skill of asset managers, and the asset's complexity can play crucial roles in the realization or mitigation of financial risks (OECD, 2015). Technical risk can be viewed as the "potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly established and stated performance requirements", specifically related to any one or more of the following: safety, technical, cost or schedule performance targets (NASA, 2020). Herein, the real-asset nature of infrastructure provides an increased risk profile by increasing the number of opportunities for technical risks to materialize. It should also be noted that technical risks can have overlapping implications with financial risks - as Amyotte and McCutcheon (2006) point out, technical risks can (and often do) have financial implications, such as impacts to revenue stream realization caused by delivery schedule delays. This understanding of financial and technical risks is a critical condition of infrastructure assets, where financial implications of technical risk intersect with prudent management of the overall asset risk profile.

a) Asset risks in practice

The risk profile of an asset will be a combination of both the financial and technical risks. When viewed holistically, this forms the basis of the asset management practice. Asset management describes a process by which an organization's assets are leveraged to deliver value and achieve their business objectives (The Institute for Asset Management, 2015). Asset management's principles highlight that technical knowledge of a real asset alone is not sufficient to describe the discipline of asset management (AM), and that to realize its benefits for value creation from assets, management decisions must draw on a range of disciplines such as safety, business, and finance (The Institute for Asset Management, 2015). Expanding on this integrated nature of AM, The Institute for Asset Management (2015) states that to realize this value, several other disciplines need to come together to contribute to the overall AM capabilities, developing a multifaceted understanding of risk, and enabling the integration of asset and financial data. Roda and Macchi (2016) expand on this and emphasize that the AM process should be structured such that risk is considered in cost/benefit analyses related to decision making throughout the asset life.

While infrastructure is often viewed as 'an asset class' (Sawant, 2010; Weber *et al*, 2016), viewing infrastructure as a singular sector with regards to risk profiles is incorrect, and subclasses of the sector will have unique risk profiles based on revenue structure, geographic location, asset technological maturity, and asset and social environment specific characteristics (Thierie and De Moor, 2016). Additionally, the risk profile of an asset will vary throughout its lifecycle; both the probability of occurrence and the severity of outcome will fluctuate as a function of both asset-state in the lifecycle and exogenous factors, such as political shifts and macroeconomic factors (OECD, 2015). This highlights the importance in understanding the duration of infrastructure asset lifecycles; longer lifecycles provide increased opportunities for unexpected events to occur. Additionally, risks on a specific asset are generally a factor of the underlying asset characteristics, public sector contracts, and its exposure to the environment in which the asset operates. Thus, the magnitude of the risks will vary depending on the country, sector, asset maturity, and project (OECD, 2015; Thierie and De Moor, 2016).

b) Limitations of risk definitions

Risk Temporality

It has been shown that the nature of risk is constantly changing, and it is important to understand the temporal component of data monitoring. As Batty (2018) states that in the context of cities, high-frequency systems time scales operate in the real-time, with human centric time scales ("second by second, minute by minute, up to cycles of days and months"). This is in contrast with the low-frequency time scales of systems – which operate over years, decades, and longer (Batty, 2018). Understanding this temporal concept is important when determining what data is needed to support decision making and what type of discount rates were to apply in project. Industry generally accepts the concept of risk temporality as described here. Schwartz *et al.* (2014) expands on this aspect and highlights that asset risks in infrastructure generally decrease as the project progresses, driven by reduced information asymmetry as more information about the project becomes available. The OECD (2015) also passively acknowledges the temporal nature of risk by describing specific risks present at different project phases (see Appendix 1: Figure 1). However, industry practice highlights implementation limitations to this understanding, with Larew and Robson (2011) pointing out that risk models are too often abandoned after the initial investment decision, and significant value is lost by undermanaging risk throughout the lifecycle of projects (Beckers *et al.*, 2013). Flyvbjerg (2009) further addresses this issue, emphasizing that due diligence of infrastructure cost/benefit analysis should be supplemented with empirical ex-post risk analysis, but rarely are done in practice.

c) Use of the discount rate as a proxy for risks

Descriptions of risk are inherently difficult to articulate. Projects attempt to describe risk and their impacts through risk matrices and registers (Saffin and Laryea, 2012), but as Holton (2004) points out, the concepts of uncertainty and severity are limited in their operational definitions, leaving the description of risk to be shared using proxy risk metrics. These proxy definitions may vary industry to industry, project to project, and by type of risk being described. One common proxy for risk in financial models is the discount rate (Alcaraz, 2014). Asset valuations attempt to account for both risk limitations through the use of Net Present Value (NPV) analysis. NPV analysis acknowledges the temporal value of money and is based on qualifying the time preference for investors (Copiello *et al.*, 2017), simply summarized as money available today is more valuable than money available tomorrow, represented by discounting future cashflows. This discounting factor is bespoken to the investment, reflecting the opportunity cost of the invested capital, and is generally expected to provide an estimate of the riskiness of the investment (Komzolov *et al.*, 2021). Thus, by using NPV instead of other common asset evaluation methods (IRR, ROI), evaluators can ensure that that the project valuation is risk adjusted (Komzolov *et al.*, 2021), and the discount rate can be seen as a proxy for asset risk.

The selection of discount rate is a key factor in NPV analysis. In the real estate context, Psunder and Cirman (2011) highlight the prominence of the discount rate in the discounting of cashflows, observing that the discount rate has an outsized impact on projects of long duration compared to those of short duration, which, given the lifespan of infrastructure, creates a dichotomy: the selection of discount rate indicates preference of how resources are allocated between present and future (Bonzanigo and Lakra, 2014). Copiello *et al.* (2017) further emphasize the significance of the discount rate, stating that the choice of discount rate is among the most sensitive parameters in building energy efficiency evaluations.

Evaluations of infrastructure projects commonly are discounted by the time-value of money, which is also known as the financial or commercial discount rate. There are scenarios where the time-value discount should consider the social opportunity costs of deployed capital instead of the purely financial considerations. In these scenarios (typically in the perspective of government, or entities acting on the behalf of the general population), analysis can be completed using the social discount rate, where analysis compares the social benefits minus social costs in the evaluation of the social opportunity costs of capital (Boardman and Hellowell, 2017). Brotherson *et al.* (2015) highlights that the use of WACC as a discount rate is only appropriate for an 'average risk' investment. Challenging the application of this is the lack of clarity of a specific investment's risk versus an average risk, and the quantification of this risk differential when incorporating it into a risk-adjusted discount rate (Brotherson *et al.*, 2015). To overcome these challenges, discount rates should be risk-adjusted, whether using market proxies (comparable) of a risk class or alternative best practices to account for these risk differences (Brotherson *et al.*, 2015). Alcaraz (2014) and Esty (1999) point out that valuation theory dictates that a projects discount rate should account for market or systematic risk; unsystematic or diversifiable risks should be reflected in the cash flows of the project. This means that project specific risks should be accounted for in the cashflow, regardless of whether they are technical or financial risks to the asset.

d) Limitations to the discount rate as a proxy of risk

Readers will note that while the NPV analysis accounts for the temporal value of money, there is limited temporal treatment of risk within the discount rate, limiting the NPV analysis to documented or anticipated risks at a point in time while in nature it should be stochastic to be temporal. Esty (1999) also raises this point, within the context of leverage variations throughout an asset lifecycle – as a project's gearing ratio changes with time, the WACC also varies year-to-year, which can cause (depending on the leverage used in the WACC calculation) the Cost of Equity to be over or under-stated at various points throughout the asset lifecycle. This is supported by Biondi (2011), who notes that series of discount rates can be used to better estimate the temporal profiles of the cost of capital in a project. However, there is a lack of consensus on how to overcome this challenge. Whether the use of a single or multiple discount rates is superior is a subject of debate; Alcaraz (2014) highlights that a lack of clarity in the implementation of multiple discount rates, possible error in estimating discount rates (whether using one or multiple), and the simplicity of implementing a single discount rate all should be considered when deciding whether to use a single or multiple discount rates.

Not all risk to an asset is captured in the discount rate proxy. Diversifiable risks still must be accounted for within the project cashflows. While not the focus of this paper, it is worth a brief mention that the temporal-variable risk characteristics of non-systematic risks match those of systematic risks as outlined above. One possible proxy to assign to these non-systematic risks is in the form of cost contingency within the cashflow model (Yescombe and Farquharson, 2018). Nonfinancial (i.e. operational) management of these risks often comes in the form of risk registers to identify and quantify the impacts of the risks. Risk registers are useful in that they can capture and track both financial and technical risks, and can highlight areas that need additional mitigation (Malarvizhi and Lavanya, 2008). However, as Saffin and Laryea (2012) identify, risk registers in construction are typically owned by project managers and updated by them or their designates, limiting their scope across the asset lifecycle phases. Risk registers should be revisited throughout the project lifecycle to revise risk details and to identify emerging risks (Yescombe and Farquharson, 2018). This methodology requires strong organizational governance to ensure alignment of risk understanding between affected parties and may be limited in the ability to understand the cumulative impact of risks on an asset, particularly across different stages of the asset lifecycle.

Discount rates theoretically equate a current stock price to an infinite series of risk adjusted future cashflows, discounted against the risk-free rate (Botosan and Plumlee, 2005). Determining an appropriate discount rate using the CAPM method is generally not directly observable without a current valuation and the market forecasts for future cashflows (Botosan and Plumlee, 2005). This creates an obvious limitation in emerging sectors: both current valuation, and market performance lack comparable data from which to determine an appropriate risk adjustment. Lucas and Montesinos (2021) support this by pointing out that projects with long-lived impact, such as those mitigating climate change, traditional market pricing may be inappropriate because of the unavailability of data. Gollier and Hammitt (2014) give the example that the economic discount rate for consumption and the ecological discount rate for environmental consequences depend on the changes in both consumption and environment and on uncertainty about these changes. Depending on maturities, they suggested a schedule of discount rates for different maturities and for long term and risky project it is the uncertainty surrounding the choice of climate mitigated discount rate.

This challenge can also be observed in assets with multi-generational impacts, where traditional discount rate determination may also be inappropriate because it overly discounts future benefits and cashflows. KPMG (2021) show that applying relatively high discount rates on intergenerational projects has the practical effect of long-term benefits and pay-outs being devalued relative to any short-term investments. Arrow *et al.* (2014) also highlight this challenge in the greenhouse gas abatement context, where costs are incurred early on in the project life but have centuries long-lasting impacts, and provide a caveated case for implementing a declining discount rate. Summarizing the challenge of time when selecting a discount rate for long-lived assets: "a higher discount rate signifies urgency to satisfy present needs, whereas a lower discount rate expresses concern for the long-term impacts of an investment" (Bonzanigo and Lakra, 2014).

Despite its importance in project evaluation, the discount rate is paradoxically a common source of uncertainty in DCF analysis (Copiello *et al.*, 2017). Viewing the discount rate as proxy for risk has general academic and industry agreement (Copiello *et al.*, 2017) and it is well understood that risks to each asset will be bespoke (Thierie and De Moor, 2016). A lack of consensus emerges with the treatment of the variable nature of risk as highlighted by (Alcaraz, 2014; Esty, 1999; Lucas and Montesinos, 2021; Gollier and Hammitt, 2014). Further discount rate disconnect from the temporal variability of risk is highlighted in Larew and

Robson's (2011) observation that often risk models are abandoned after project selection, which stands in contrast with industry acceptance that risk changes with time. Section 3 will describe the methodology used to understand the current academic and industry thought in the application of the discount rate, and determine if it aligns with the nature of risk.

3. METHODOLOGY

This section will look for alignment between the application of discount rate and its determination, and the recognition of the variable and temporal nature of asset risk. This will be conducted through a qualitative, semi-systematic literature review of academic papers that discuss discount rate selection and project valuation across multiple infrastructure and infrastructure adjacent sectors. For this analysis, risk variability will be considered as the use of multiple discount rates applied to a NPV analysis; risk temporality will be considered as the acknowledgement of the temporal-change of discount rates throughout an asset's lifecycle. A meta-review will be conducted, and literature will be examined and categorized by several key components: 1) Document source, 2) Specific sub-sector, 3) Finance scheme (corporate vs. project), 4) Use of social or commercial discount rate, 5) Acknowledgement of risk variability or temporality, and 6) If acknowledgement in category (5), the proposed application or solution for risk variability or temporality. Additionally, literature will be examined for discussion of the risk variation, and reasons for its application (or not). This review will focus on economic infrastructure for the purposes of definitional clarity. Inclusion criteria in the literature review can be found in Table 1. This review of academic literature is to be conducted utilizing several academic databases, including GaleOne File, ProQuest, and the Web of Science.

Literature Attributes	Criteria	Rational
Year	*Since 2017 (past 5 years)*	*To examine latest academic thought*
Source	*Peer-reviewed academic journal*	*To examine the latest positions of academic thought*
Infrastructure Sub-Sector	*Economic infrastructure involving the Transport, Energy, Resource Extraction, Carbon/Climate Mitigation, Social, Solid Waste Management, Water, and Digital sectors*	*To include a broad examination of the topic across multiple infrastructure sectors*
Topic	*Discount rate determination, Asset/Project Valuation/Feasibility, Value for Money (VfM) Analysis*	

Language	*English*	
Keywords	*Discount rate, cost of capital, cost of equity, AND infrastructure, built environment*	*Searches included several database specific variations on these thematic terms, to account for spelling, pluralization, etc.*
Removed Keywords	*Land use, urban planning, COVID*	*Search terms returned removed several thematic terms that were returned results, but not related to the specific literature review*

TABLE 1: Literature selection criteria for Review 1

Additionally, a search of multi-lateral development bank (MDB) publications will occur to understand their methodology used for discount rate selection. The search date criteria is relaxed for these organizations to find the latest available documents, as published guidance may not be regularly updated. Selected documents will be analysed the same as the academic review. The multi-lateral publications searched are the European Investment Bank (EIB), The International Bank for Reconstruction and Development, and the Asian Development Bank (ADB). These represent the largest MDB's, by total assets (Kenton, 2021). The International Bank for Reconstruction and Development leverages World Bank assessment methodologies, and as such, World Bank documents were selected for this organization. A second, broad literature review examining the temporal-variable nature of systemic risk will also be conducted, specifically looking for references to the dynamic nature of systemic risk, defined as 'Dynamic Discount Rates'. This search will be conducted utilizing the academic databases and internet searches of scholarly articles. This search will expand on the definition of infrastructure and look for references in social infrastructure and real-asset infrastructure adjacent fields, to look for related concepts which may be applied to the economic infrastructure field. The search parameters for the second review can be found in Table 2.

Literature Attributes	**Criteria**	**Rational**
Year	*Since 2012 (past 10 years)*	*Expanded date range given the topic novelty*
Source	*Peer-reviewed academic journal*	*To examine the positions of academic thought*
Topic	*Dynamic Discount Rate*	
Language	*English*	
Keywords	*Dynamic discount rate*	*Searches included several database specific variations on these thematic terms, to account for spelling, pluralization, etc. Sectoral*

		context omitted from search
Removed Keywords	*Land use, urban planning, COVID*	*Search terms returned removed several thematic terms that were returned results, but not related to the specific literature review*

TABLE 2: Literature selection criteria for Review 2

Holistically, the information from these two reviews will be used to look for trends in the infrastructure sector's ability to understand asset risks in relation to asset financing, and to better understand any application and trends across the greater infrastructure finance ecosystem. The review of literature is broken down into two results, based on the two searches completed. Appendix A provides the results of the first review.

In total, 64 sources were analyzed within the first literature review. The breakdown of the sources: 61 ea. were academic journals, and 3 ea. were multi-lateral development bank investment guidance documents. Academic articles ranged widely in topic, and included case studies, value-for-money analysis, theoretical papers, project feasibility assessments, and policy analysis. MDB documents were in form of guidance documentation or organizational research papers. Geographic coverage of literature was large, with studies of infrastructure included from every continent except Antarctica. Similarly, there was a broad range of economic maturity of countries in reviewed projects, and asset scope (size). The diversity of findings was important, to maximize the understanding of the risk parameters in question.

Sectorally, 19% of the reviewed documents discussed assets to help mitigate climate change, 28% were involved energy assets, 28% transport, 13% water, and 20% did not specify a sector[1]. A breakdown of the context can be found in Table 3.

Sub-Sector	***Count of Sub-Sector Application***
Climate	*9*
Climate / Energy	*1*
Climate / Transport	*1*
Climate / Water	*1*
Energy	*15*
Energy / Transport	*2*
Transport	*15*
Water	*7*

[1] Because several papers addressed multiple sectors, the total is more than 100%.

Not Specified	*13*
TOTAL	***64***

TABLE 3: Breakdown of reviewed literature by sub-sector

4. MAIN FINDINGS

a) Discount rate determination, Asset/Project Valuation, VfM Analysis

i. Financial discount rate treatment of the variable-temporal nature of risk

Most applications of the financial discount rate used a singular discount rate in DCF analysis. Of 40 references to the implementation of a financial discount rate, just 1 (2%) referenced using multiple discount rates (Reis and Shortridge, 2021). Two additional documents discuss the variable nature of risk, proposing a quantification of systematic risk though an alternative methodology (Espinoza *et al.*, 2020, Espinoza *et al.*, 2019). Though applying a singular discount rate, this revised methodology to the DCF analysis (named Decoupled Net Present Value) aims to achieve similar outcomes as the multiple discount rates; as such, these articles were considered to address the variable nature of risk. Almost universally, asset financial analyses included a sensitivity study performed on the discount rate to understand impacts of multiple risk realization scenarios on project financial performance. In all cases this was a simple test, performed by varying the discount rate across a range of values consistently across the asset life to understand the impact to financial performance.

Temporal management of systematic risk throughout the asset lifecycle was not mentioned in any of the literature where financial discount rates were applied. In many cases, this is reflected by the nature of the literature, which often was assessing project financial feasibility, focused on the early investment analysis.

ii. Social discount rate treatment of the variable-temporal nature of risk

When social discount rates were applied, there was much less consensus regarding the use of a single or multiple discount rate. Out of 13 cases where the social discount rate was utilized, multiple discount rates were applied in 6 of them. This finding is aligned with the results of Mouter (2018), who in his analysis of 5 European countries' application of the social discount rate found that governmental guidance in 2 of the 5 countries applied a single discount rate, and 3 of the 5 countries instructed the use of multiple discount rates for project analysis.

The rationale of multiple discount rates was widely in line with the findings of literature (see section 2) and justified on the grounds of accounting for multi-generation benefits realized from the investments.

The two sources that reference both the use of multiple discount rates and acknowledge the temporal variability of risks in assets both apply a social discount rate. Goldmann (2017) provides a methodology for developing a social discount rate, corrected for systematic risk in transportation infrastructure. Though she does not directly adjust for the temporal changes to this discount rate, she does suggest future research to account for the incorporation of a time-varying coefficient in the process of selecting a discount rate. Stern (2018) suggests that dynamic analysis of intertemporal issues and values of public policies regarding the financing of infrastructure must be undertaken to address urgent challenges presented by climate change. Here again, the specific argument for monitoring infrastructure assets throughout its lifecycle is not directly suggested, but rather acknowledgement that government policies are critical to a low-carbon transition, and the discount rate must be updated to accurately reflect the impacts of those policies. Interestingly, both of these papers were presented in the context of the public perspective.

iii. Analysis perspective and the application of risks

In general, roughly 40% of reviewed papers did not explicitly provide a perspective of whether analysis was conducted from the public or private investor view, as seen in Table 6. However, where it was, the discussion of discount rates selection highlights the importance of viewpoint.

Perspective	***Referenced single discount rate***	***Referenced to multiple discount sate***	***References to temporal variation of discount rate***	***Reference to multiple discount rate and temporal variation of discount rate***
Public	*17+1^*	*1^*	*1*	*2*
Private	*6*	*2*		
MDB	*2+1**	*1**		
Various	*4*			
Not Specified	*21*	*7*		

TABLE 4: Literature Perspective vs.. application of risk variability or temporality Counts with (,^) are from sources that discuss multiple applications of discount rates.*

The use of discount rates by multilateral banks seems to take on a slightly different viewpoint than academic literature, which aligns with their perspective of finance. The World

Bank highlights that the 10-12% discount rate typically applied to projects reflects a notional discount rate, which does not necessarily reflect the real opportunity cost of capital or risks applied (Belli *et al*., 1998). The EIB addresses both social and financial discount rates (Sartori, 2021). It suggests leveraging country or sectoral specific discount rates when implementing a financial discount rate. Social discount rates are a set value for projects, but guidance does allow for a time-decreasing discount rate in long-lived assets to account for long-term benefits. Interestingly, the EIB states that systematic risks should not be reflected in the discount rate when applying a social discount rate, rather these should be accounted for in the project's risk register (Sartori, 2021). This logic is supplemented by the guidance to apply a single social discount rate across sectors within a country: because the social discount rate represents the opportunity cost of resources across all societal (governmental) spending, it must remain consistent across sectors to standardize the social rate of time preference (Sartori, 2021). The ADB uses a single discount rate, leveraging the WACC of the project, not the entity, though acknowledges the presence of risk by dictating the use of sensitivity analysis to understand risk impacts to the project (Asian Development Bank, 2013). These organizations are rarely involved in the management of the project, and generally focused only on the decision to provide financial support – this perspective limits their need and demand to account for the variable and temporal nature of risk through an asset's lifecycle, as they are not typically involved in the active management to maximize an assets value-for-money.

Despite the need for private financers to maximize financial returns, there was limited discussion of accounting for systematic risk through the use of multiple discount rates, or any discussion of actively tracking this through asset lifecycles.

b) Dynamic discount rate

The second review of literature, which focused on 'dynamic discount rates' retuned only four results. Of these four sources, two were from the extractive industries (mining and oil/gas projects), and two provided sectoral-wide infrastructure application. All four sources were in the context of private investment or to improve project finance project's access to private capital. In all cases, the financial discount rate was applied.

Though this search was intended to investigate current thought on the temporal monitoring of risk through a real asset's lifecycle, none of the articles directly address this concept. One of the four proposes a methodology whereby to leverage risk tracking to improve investor confidence when deciding to invest in an asset (Mukherjee *et al.*, 2015). The remaining three provide methodologies to dynamically alter the discount rate early in the asset life to either improve valuation accuracy (Ardian and Kumral, 2018, Li *et al.*, 2020b), or to optimize public subsidies applied to public-private partnership (PPP) infrastructure projects (Zhang *et al.*, 2021).

The work of Mukherjee *et al.* (2015) proposes a methodology to track the risk profile of infra-assets outside of the DCF or discount rate, but states that the risk model presented can be used to influence the risk premiums demanded of investment in an asset. Li *et al.* (2020b) and Ardian and Kumral (2018) propose methodologies that directly impact the discount rate in a DCF model. Finally, Zhang *et al.* (2021) proposes a methodology whereby a 'dynamic discount rate', accounting for the inflation and interest rate changes, can be used to optimize the size of government subsidies to make PPP-projects financially feasible to investors.

Three of the four papers apply stochastic (probabilistic) modelling to address the unknowable nature of future risk (Ardian and Kumral, 2018, Zhang et al., 2021, Mukherjee et al., 2015). The fourth applies a calculated 'risk coefficient' to the risk-free rate of return to develop a year-specific discount rate (Li *et al.*, 2020b) . In all cases, the concept of 'dynamic discount rate' was used to account for the temporal-variation of risk throughout an asset's lifecycle, but did not propose continuous monitoring of asset risk past the project start.

5. THE ANALYSIS

The analysis of the literature reviews show that the systematic risk variation and temporality of infrastructure projects are generally only tacitly acknowledged in practice. The majority of literature sees the use of a singular discount rate applied throughout the asset lifecycle, examined at a singular point in time (typically examining the asset investment feasibility). Risk variability is tacitly acknowledged through the performance of sensitivity analysis on the discount rate (examining the financial feasibility of an asset through a range of discount rates), which were consistently performed in the reviewed literature, even if asset analysis was completed using a singular discount rate. Sensitivity analyses do provide valuable insights into the impact of systematic risks on an asset, but there are limitations on the extent of this review. Sensitivity tests of an asset on a singular discount rate assume that the discount rate is adjusted consistently across the asset lifecycle and does not reflect the real-world conditions of risk variation throughout said lifecycle.

a) Multiple Discount Rates and Risk Variability

The use of multiple discount rates is most commonly applied when implementing a social discount rate. Widely, this is to account for the multi-generational impacts of infrastructure, in line with literature observations (KPMG, 2021; Arrow *et al.* 2014; Bonzanigo and Lakra, 2014). There does not appear to be any clear application trend by specific sub-sector, with almost half the references to the use of multiple discount rates absent of sectoral context. Where a sector was applied, it was primarily in the transportation or climate mitigation infrastructure fields. The reference to multiple discount rates when leveraging financial discount rates is extremely limited, and in only one case is applied to a specific sector (Reis and Shortridge, 2021). This limited application to specific projects and sectors indicates the use of multiple financial discount rates is novel, and continues to be probed broadly across the field of infrastructure investment.

Whether to use a singular or multiple discount rate remains a point of discussion in academic literature. This review sees consistent usage of a singular discount rate, which can be explained by the complexity of, and lack of consensus around the application of, multiple discount rates (Alcaraz, 2014). When leveraging a financial discount rate, this is particularly apparent, perhaps in line with the observation that a singular discount rate does exist that would match the outcomes of when multiple discount rates are applied in analysis' (Alcaraz, 2014). While these concerns make logical sense, the reality of chronic mismatches between asset performance and financial projections highlighted by Flyvbjerg (2009) suggests there are opportunities for improvement when incorporating risk into financial modelling practice. Particularly in the cases of long-life or complex assets, the practice of asset management and need to actively manage risks throughout an asset's life promote the argument for leveraging multiple discount rates throughout an asset's lifespan to reflect the real nature of systematic risks on asset financial performance.

b) Dynamic Discount Rates and Risk Temporality

The debate of whether to use a single or multiple discount rates across an asset lifecycle aside, this review suggests that current methodologies are focused on evaluating risks to assets at a singular point in time, typically at project concept inception or for funding evaluation decision making. This stands at odds with the needs of industry, which observes that in order to maximize value of real-assets, risks must be actively managed throughout the lifecycle.

Where the concept is directly addressed, the discussion of temporal management of discount rates is presented in the context of the private sector, as seen in the second review. Discussion of dynamic discount rates is discussed in the Public Private Partnership context, and in areas of direct private investment in assets. When analyzing such investments from the public perspective, it is done in the context of evaluating the optimal public subsidy for PPP projects, or to assess the effectiveness of the PPP framework; did the decision to leverage PPP funding result in the expected value for money? Much of the remaining literature where dynamic discounting is directly referenced focuses on the application in extractive industries (oil/gas and mining). While not directly in infrastructure, these fields are infrastructure adjacent, and share many characteristics (real-assets, long lifecycle). In all cases of private perspective, the use of dynamic or temporally varying discount rates is presented in the context of maximizing or realizing asset value. This recognition of the temporal fluctuations of systematic risk in assets promotes the argument for inclusion of such analysis of long-lived assets.

Where temporal management of risk is presented in the public context, the discussion remains more theoretical, proposing the concept of public monitoring of systematic risk. This shows that successful delivery of assets is important to the public, but there remains work to be done to understand how this should be practically managed. One additional paper was found discussing the handling of dynamic risks in the purely public context (Szajnfarber *et al.*, 2022). This suggested another layer of analysis (Evolvability Analysis Framework) to introduce policy considerations into management decisions, and was not focused directly on the temporal-dynamic nature of the discount rate[2].

Taken together, these findings suggest that there are real opportunities to improve investment value by actively tracking asset risk and providing visibility for mitigations. It also indicates there may be future opportunity in the public sector to leverage such methodologies to improve asset-management decisions as understanding of the dynamic nature of risk becomes more developed. The discussion of temporal management of risk highlights the opportunities presented by probabilistic modelling to forecast a range of possible future

[2] For this reason, this document was excluded from the literature review. However, its discussion of the temporal nature of risk and uniqueness of perspective compared to other literature warrants mention.

outcomes. This is supported by the works of Suo *et al.* (2021), Chen *et al.* (2021) and Deveci *et al.* (2023) and their discussion of the ability of stochastic modelling to quantify risk in complex and interdependent asset systems and decision making. While providing improved ability to account for a range of forward-looking risk unknowns, stochastic modelling on its own does not provide the ability to provide updated visibility on the real risks observed by assets throughout their lifespan. As such, while a useful tool to leverage when quantifying future risk, it does not directly provide visibility into the temporal monitoring and active mitigation of risks arising throughout an asset's lifecycle.

c) Risk Management and the Role of Perspective

The results of the MDB's guidance highlights the importance of perspective in the discussion of risk. Their involvement in reviewing an asset's risk profile is generally concentrated at a point in time, when deciding to provide financial support to a project. Because of the focus of MDB on resolving market failures and bridging the welfare gap utilizing infrastructure, there is a larger focus on asset impacts on community, welfare, and social good. This perspective focus, along with common terms of finance, leads to limited role in the management of risks where the day-to-day management falls to the asset owner. This position stands in contract with asset owners or private investors who seek benefit (or profit) maximization, which creates incentive to increase an asset's value-for-money (VfM) in order to maximize investment returns. The active understanding of risk falls to the party responsible to manage it.

While outside the direct scope of this review, this understanding of perspective in preference and risk tolerance in the selection of discount rates highlights the inherent significance of discount rate selection. The selection of discount rate is a complex decision when conducting a financial analysis of a real-asset, reflective of the dynamic and variable nature of the risk it represents. Equity funding is commonly required by lenders to unlock debt, but because of its lack of recourse is more sensitive to the variable nature of risk, and thus more sensitive to the discount rates used. Thus, the ability to articulate and mitigate risks becomes a key component of infrastructure financing; improving tools to accurately do so could provide opportunities to increase capital available for infrastructure investment.

Mukherjee *et al.* (2015) states that "(if) dynamic behaviour of projects, its management, and hence its associated risk can be characterized, quantified, and monitored in a more accurate manner, the transparency and understanding will result in meaningful assessment of risk profiles and result in appropriately priced risk premiums …", expanding the market for infrastructure investment by attracting more participants. The need to track, quantify, and provide visibility of asset risk is clear - improving private sector confidence in investment decisions is key to closing the funding gap in the infrastructure sector. As this paper has found, the current applications of the discount rate in financial analyses provide practical limitations to this objective. Next section will provide a possible framework whereby industry is able to visualize asset risk and use this information to inform management mitigations throughout the lifecycle.

d) Incorporating Systematic Risk into Digital Twin modelling

As seen in the background literature, there is recognition of the dynamic nature of risk in infrastructure assets. Further, asset management principles, academic literature and industry recognize the importance of actively managing risks throughout an assets lifecycle. The findings of this paper challenge the implementation of this principle by showing a widespread use of a static discount rate in financial analyses, in line with industry observations that financial analyses often do not continue past the decision to invest. Advances in computing power and asset performance visibility provide a path by which accurate understanding of the assets systematic risk profile can be calculated and leveraged throughout the lifecycle to inform management decisions, increasing opportunities to influence performance.

One possible solution to improve risk visibility is to incorporate financial proxies of risk and performance into digital twin (DT) tools. Digital twins are a digital representation of a physical asset (or their delivered services), which is used to make decisions that will affect the said asset (Barnett, 2020; Yan *et al.*, 2022). The concept can be expanded to highlight the digital independence from the physical asset, where digital information mirrors ('twins') the information embedded in the physical system, and operates throughout the entire lifecycle of the system (Grieves and Vickers, 2017). Today, such tools are used to influence maintenance and management decision on assets where DTs are incorporated. Such digital frameworks could be expanded upon to include financial metrics to track an asset's financial performance throughout its' lifecycle, including modelling its cashflows and NPV to provide a regularly updated valuation of the asset. Such a framework could integrate data already collected by 'smart' assets and incorporated into existing digital twins, with new sources of data to provide updated asset valuations. Key to this concept is to use the latest underlaying data to understand the financial performance of assets. By breaking down the components of DCF valuations at a high-level, a possible (simplistic) example is outlined below.

i. **Cost estimation:**

Real and estimated asset costs throughout the lifecycle can be tracked and incorporated into the cost component of the DCF model. Besides the obvious leveraging of actual, historical cost data, forward looking estimates of costs can also be incorporated over the duration of the asset life. Through construction, this could be in the form of revised estimates, accounting for adjustments to construction timelines, scope changes, or changes to input values (i.e. labour cost adjustments). During the operational phase of the asset, real maintenance costs can also be tracked and incorporated, but the real power of the financial twin would come from maintenance cost prediction capabilities of such a model. A combination of predictive maintenance responses (based on asset conditions found via asset monitoring, incorporated in a digital twin), combined with stochastic treatment of future maintenance demand scenarios, could be used to regularly extract updated asset cost profiles across the lifecycle. Costs forecasts could further include macro-tracking of non-asset factors, such as severe weather impacts and resource cost information.

ii. **Revenue estimation**

Asset revenues can similarly be captured and integrated into the financial twin model. Actual revenues can be tracked, but again, forward looking revisions can be incorporated into the financial twin to track expected performance. These could be simplistically applied via forward projections of historical utilization data, but could incorporate dissimilar data sources that could impact future demand, including factor such as the regional population changes, developments in technology alternatives, or user preference.

Before continuing to remaining component of the valuation model, the value considerations of temporally aligning updated asset cost and revenues (including those driven by a variety of dissimilar inputs, such as weather, utilization, physical condition, technology maturation) regularly can allow for value tracking over time, and mitigation if warranted. If revenue predictions show a variation in expected, cost impacts can be examined to maintain levelized asset value. This could come in the form of adjusted maintenance practices (i.e.. lowering expected spend in the case of decreased utilization), offering backing to proactively renegotiating applicable contracts (either affecting costs or revenues), or to justify costs to improve asset resiliency. Regardless of mitigations implemented, such a model allows for a holistic picture of asset performance and allows for efficient scenario testing to review the impacts of a variety of financial, operational, or technical mitigations to effectively direct management efforts.

iii. Asset Risks

Asset risks could be incorporated in two ways, in line with valuation best practices. Asset systemic risks can be incorporated into a variable discount rate, and non-systemic risks can be incorporated into the into the appropriate cost or revenue categories outlined above. Systemic risks affecting assets can be incorporated into the discount rate. Regardless of the method used to determine the discount rate, the underlaying data in its determination can be updated on a periodic basis to provide a view of current risks upon the asset. As identified in the background literature review, the discount rate is a critical factor impacting valuation, particularly in the case of long-lived assets; an up to date understanding of this risk profile (and the impacts to the discount rate) is critical for accurate valuation and provides opportunities to mitigate (or benefit from) evolving macroeconomic realities.

Non-systemic risks captured as a contingency line item provides financial flexibility to respond to a variety of possible risk realizations but is limited in its ability to provide insights into the weight of various risks. By incorporating non-systemic risks into such a model, they can be assigned as an input on the underlying metrics of the relevant line item, providing increased understanding of the nature of this risk, and its overall impact on the asset valuation.

Such a concept would incorporate updated inputs into the cashflows (such as utilization rates impacting revenues, or actual and forecasted maintenance costs) and assign and track systematic risks to the asset in the form of a forward-looking, dynamically changing, discount rate. When combined, this information can provide an updated asset valuation, which, when tracked over time, can provide a view of asset financial health. Integrating this variety of dissimilar data sources into an updated, single view of an asset's financial performance throughout its lifecycle gives rise to the concept of 'financial twin'. In tandem with existing digital twin work, the 'financial twin' could give an unprecedented insight into asset performance, integrating asset operational, utilization, and financial data. Using such a concept, divergence of asset financial performance from expected can be tracked in near-real time and used to isolate the causal risk factors to allow for mitigations to be enacted promptly.

The treatment of risks in a financial twin likely supports the use of multiple discount rates to temporally vary systematic risk throughout an asset's life; within reason, the more nuanced and controlled the model, the more accurate it will be[3]. To develop the concept of a financial twin further, several concepts will need resolution:

- Risk temporality: A greater understanding of systematic risk temporality is needed. Further expanding on the Batty (2018) discussion to "incorporate social and economic processes with the built environment, and to link functional and physical processes to socio-economic representations" between high-frequency, human-centric and low-frequency, asset-centric time scales, a greater understanding of the appropriate temporal cadence of risk impacts and opportunities for enacting mitigations is needed.
- Implementing multiple discount rates: As highlighted by Alcaraz (2014), there remains a lack of consistency on the appropriate implantation of multiple discount rates. While this may be bespoken to an organization, clarity and some level of standardization will become critical if the concept of financial twins is to become more widespread, particularly the opportunity to integrate data between interconnected assets is realized.
- Financial interconnections of system assets: infrastructure rarely exists as a standalone entity, and often sits within a greater 'system of systems' ecosystem, where end-value is provided by several intra- or interdependent assets (Guo and Haimes, 2016), where ownership can span multiple companies or even multiple industries (Moteff, 2005). Enhanced understanding of interrelated decision impacts and risk mitigation strategies across multiple interconnected assets will be useful to maximize the financial twin potential.

There are several benefits to the financial twin concept. First, it allows for an asset-level overview of riskiness and can incorporate both systematic and non-systematic risks in their respective forms. The systematic risk factors can be incorporated into a dynamically updating discount rate; non-systematic risk factors can be accounted for in the cashflows.

[3] The concept of model simplicity outlined in Occam's Razor should be considered, but the ability presented by multiple discount rates to more accurately model complex asset financials, and the ability of recent advances in computing power to handle the analysis, remove many of the concerns regarding their use and support their implementation.

Quantification of systematic risks can occur within the typical methodology of the organization to determine the discount rate; the key rational is to update the discount rate to leverage a consistent methodology, using the latest *a priori* information to look forward. The second benefit is the temporal monitoring does not need to be aligned between all model inputs – such a model is able to accept the best information available. This feature is particularly useful when considering risk temporality is not consistent across risk types; currency exchange rate risks will most certainly have a different temporal cadence than demand risks. Similarly, the reaction of management to different risks will most certainly require different temporal responses .Third, such a system can be designed to align with the system-of-systems nature of infrastructure assets as defined by Guo and Haimes (2016), where financial and risk management monitoring of a particular asset are able to incorporate and account for relevant inputs from related assets, even those spanning multiple companies or industries. Fourth, the financial twin's presence throughout an asset life minimizes practical implementation challenges presented by risk registers. By providing an objective, consistent view of the risk profile throughout the asset's life, risk register ownership and management challenges presented by Saffin and Laryea (2012) can be minimized. Finally, a financial twin can be leveraged for scenario planning and analysis, whereby testing mitigation strategies for identified risks, and their impact to asset financial performance. Here, the incorporation of forward looking, stochastic modelling can help further describe possible future states by providing a range of outcomes, to acknowledge the future ambiguity.

Where digital twin technologies enable a virtual environment to improve decision making, their usefulness can be expanded with the financial twin concept to help managers assess the financial performance of infrastructure assets throughout the lifecycle. Specifically giving visibility in near-real time to the asset risk profile by tracking the risk factors influencing the asset's discount rate can promote opportunity for active management of risk through all stages of development and operation to maximize the value for money of the asset, in line with the principles of asset management. It should be acknowledged such a financial twin is likely only appropriate in the context of very complex projects (either technically or financially), as the model itself is likely complex to build and straightforward projects likely will not justify the costs to design, build and maintain such a model. However, in the cases of complex, long-lived systems, the financial twin model can help synthesise the risk profile of an asset at a variety of management-hierarchical viewpoints. This understanding of the risk profile, and opportunity provided to enact mitigations throughout asset's life can increase investor confidence and returns, essential elements to unlocking private finance and help close the infrastructure investment gap. Thus, successful development of the financial twin concept could help close the observed gap in infrastructure funding.

6. CONCLUSION:

This paper has reviewed characteristics of asset risks in infrastructure, described in investment decisions through the discount rate. It has examined common methodologies for applying the discount rate, and limitations in the current uses of discount rates as a proxy for systematic risk, specifically on its variable and temporal nature. A thorough literature review has been conducted in two parts: first, a detailed examination of current academic and MDB practice was conducted through a semi-systematic literature review, looking at the prevalence of applying multiple discount rates and the temporal management of discount rates in literature. Second, a broad search for the use of dynamic discount rates in academic literature was conducted to understand the prevalence of active management of systematic risk.

There remains a large amount of variability in the selection of a discount rate for infrastructure asset investments. Despite the importance of the discount rate on investment decisions, this ambiguity is reflective of the bespoke nature of investments in this sector, and the risk tolerance and perception of individual investors. Perhaps more-so because of this ambiguity, the discount rate presents an opportunity for monitoring and management throughout an asset's lifecycle to optimize its' value position. When seen as a proxy for the risk of an asset, the discount rate represents a dynamic metric, one which varies temporally and lacks opportunity for diversification. These traits of the discount rate highlight the need to monitor it throughout the asset lifecycle: clear understanding of the risk profile is critical to the prudent management of assets. The results of this research show that it is common practice to apply a singular discount rate consistently across asset lifespans in infrastructure valuation analyses, reflecting risk characteristics of an asset at a point in time, rather than aligning them with the temporal-variable nature of risk. This application of a singular discount rate is at odds with the needs of industry to quantify, understand and mitigate asset risk to increase project value throughout the asset's life, a view supported by asset management theory.

Finding opportunity to expand the active management of the discount rate, this paper has then presented the concept of a 'financial twin', whereby an asset's holistic risk profile can be comingled with real performance data, and financial performance critically examined in comparison to the expected. This integration of asset performance, risk and financial data provides a multi-disciplinary view of an asset, and provides a practical opportunity to increase value in-line with asset management principles. In addition to allowing for improved management oversight and the implementation of risk mitigations, such a tool also allows for enhanced, complex scenario testing, offering insights beyond what can be found in a traditional sensitivity analysis. The 'financial twin' concept, while requiring some concept resolution, provides a framework architecture to realize enhanced asset value, in line with the practice of asset management, by reducing the information asymmetry present in an investment. This ability to manage risk and increase asset (investment) value may encourage more sectoral investment – key to solving the funding gap in infrastructure.

The final quantification of discount rate will be bespoken to an organization and investment, based on their investment needs and preferences. Regardless of the methodology used to select discount rates, risk can be tracked and managed through a financial twin in order help increase asset value.

Limitations

Several limitations to our research exist. First, the scope of review omitted social infrastructure, such as hospitals and schools. The principles examined may have implications across the broader field of infrastructure, and for assets with infra-like characteristics. Expanding on this, by limiting the scope of the review to economic infrastructure, the authors limited the search for understanding of the variable-temporal nature of risk to current work in the sector. This application was critical to enhance understanding of the current state of application within the field of infrastructure, but also limits opportunity for cross-sectoral knowledge sharing to build on work being explored in of risk research being conducted outside the context of infrastructure. Secondly, this paper has not reviewed the many methodologies for quantifying a discount rate, nor does it postulate a 'correct' methodology - this remains a perspective specific parameter. Third, due to limitations of time and scope, this paper does not provide an analytical, quantitative presentation of the financial twin, only proposing its theoretical framework. This presents opportunities for future research.

Future Research

Given the novelty in the concept of temporal monitoring of risk in infrastructure assets, opportunities for future theoretical research exist into the mechanics of such approaches, including the correct applications of risk monitoring to a cashflow model and the appropriate temporal cadence of monitoring to influence management decision-making. Similarly, continued exploration of the mechanisms by which multiple discount rates are applied within a cashflow model is warranted, particularly within the context of long-lived infrastructure assets. Additional study of the quantification of discount rates is also warranted, in line with the lack of consistency within industry around the selection of discount rate, and expanding on the work of Makovsek and Moszoro (2018) around efficient risk transfers between public and private parties. Finally, the concept of financial twin offers opportunities to build on theoretical investigations, needing practical design and development work to expand conceptual frameworks into usable tools.

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APPENDIX 1: Figures and Tables

<table>
<tr><th>Risk Categories</th><th>Development Phase</th><th>Construction Phase</th><th>Operation Phase</th><th>Termination Phase</th></tr>
<tr><td rowspan="8">Political and regulatory</td><td>Environmental review</td><td>Cancellation of permits</td><td rowspan="3">Change in tariff regulation</td><td>Contract duration</td></tr>
<tr><td rowspan="3">Rise in pre-construction costs (longer permitting process)</td><td rowspan="3">Contract renegotiation</td><td>Decommission</td></tr>
<tr><td>Asset transfer</td></tr>
<tr><td colspan="2">Currency convertibility</td></tr>
<tr><td colspan="4">Change in taxation</td></tr>
<tr><td colspan="4">Social acceptance</td></tr>
<tr><td colspan="4">Change in regulatory or legal environment</td></tr>
<tr><td colspan="4">Enforceability of contracts, collateral and security</td></tr>
<tr><td rowspan="7">Macroeconomic and business</td><td>Prefunding</td><td colspan="3">Default of counterparty</td></tr>
<tr><td colspan="2" rowspan="3">Financing availability</td><td colspan="2">Refinancing risk</td></tr>
<tr><td colspan="2">Liquidity</td></tr>
<tr><td colspan="2">Volatility of demand/market risk</td></tr>
<tr><td colspan="4">Inflation</td></tr>
<tr><td colspan="4">Real interest rates</td></tr>
<tr><td colspan="4">Exchange rate fluctuation</td></tr>
<tr><td rowspan="6">Technical</td><td colspan="3">Governance and management of the project</td><td rowspan="5">Termination value different from expected</td></tr>
<tr><td colspan="3">Environmental</td></tr>
<tr><td>Project feasibility</td><td rowspan="2">Construction delays and cost overruns</td><td rowspan="2">Qualitative deficit of the physical structure/ service</td></tr>
<tr><td>Archaeological</td></tr>
<tr><td colspan="3">Technology and obsolescence</td></tr>
<tr><td colspan="4">Force majeure</td></tr>
</table>

FIGURE 1 Classification and timing of risk linked to infrastructure projects (OECD, 2015)

APPENDIX A: Results of First Literature Review

SOURCE	SUBSECTOR	FINANCE SCHEME	PUBLIC OR PRIVATE PERSPECTIVE	TYPE OF DISCOUNT RATE	RISK TEMPORALITY OR VARIABILITY	CITATON
JOURNAL	Transport	Not specified	Public	Social	No	(An and Park, 2021)
JOURNAL	Energy	Project	Various	Social	No	(Badasyan, 2018)
JOURNAL	Energy	Not specified	Not Specified	Financial(implied)	No	(Beckers *et al*., 2021)
JOURNAL	Water	Various	Various	Financial(implied)	No	(Bekoe *et al.,* 2021)
JOURNAL	Climate	Not specified	Not Specified	Financial(implied)	No	(Berghout *et al*., 2017)
JOURNAL	Not specified	Project (PPP)	Public	Social	No	(Boardman and Hellowell, 2017)
JOURNAL	Not specified	Not specified	Not Specified	Financial(implied)	No (with caveat)	(Boomen *et al.,* 2021)
JOURNAL	Water	Not specified	Not Specified	Financial(implied)	No	(Cardenes *et al.,* 2020)
JOURNAL	Energy	Not specified	Not Specified	Social	No	(Cherbonnier and Gollier, 2022)
JOURNAL	Transport	Various	Various	Not Specified	No	(Chi and Bunker, 2021)
JOURNAL	Climate	Not specified	Not Specified	Social	Variable	(Dawson *et al.,* 2018)
JOURNAL	Not specified	Not specified	Not Specified	Financial(implied)	Variable (with caveat)	(Espinoza *et al*., 2019)
JOURNAL	Not specified	Not specified	Not Specified	Financial(implied)	Variable (with caveat)	(Espinoza *et al.,* 2020)
JOURNAL	Not specified	Not specified	Not Specified	Not Specified	No	(Ferreira Savoia *et al*., 2019)
JOURNAL	Water	Not specified	Public	Financial(implied)	No	(Godyń *et al*., 2022)
JOURNAL	Transport	Not specified	Public	Social	Temporal, Variable	(Goldmann, 2017)
JOURNAL	Energy	Not specified	Private	Financial(implied)	No	(Gruber *et al.,* 2022)
JOURNAL	Climate	Not specified	Public	Social	No	(Ha *et al*., 2021)

SOURCE	SUBSECTOR	FINANCE SCHEME	PUBLIC OR PRIVATE PERSPECTIVE	TYPE OF DISCOUNT RATE	RISK TEMPORALITY OR VARIABILITY	Citation
JOURNAL	Transport	Project (PPP)	Public	Financial(implied)	No	(Hu and Han, 2018)
JOURNAL	Energy	Not specified	Not Specified	Financial(implied)	No	(Jorge Patricio *et al.,* 2018)
JOURNAL	Climate	Not specified	Not Specified	Not Specified	Variable	(Katz, 2017)
JOURNAL	Energy	Not specified	Public	Financial(implied)	No	(Kljajić *et al*., 2020)
JOURNAL	Energy	Not specified	Not Specified	Not Specified	No	(Lai *et al*., 2017)
JOURNAL	Not specified	Not specified	Not Specified	Financial(implied)	No	(Li *et al.,* 2020a)
JOURNAL	Climate	Not specified	Public	Financial(implied)	No	(Lincke and Hinkel, 2018)
JOURNAL	Not specified	Project (PPP)	Not Specified	Financial(implied)	No	(Luo *et al*., 2021)
JOURNAL	Energy	Not specified	Public	Social	No	(Maalim *et al*., 2021)
JOURNAL	Transport	Not specified	Not Specified	Not Specified	No	(Matos Silva *et al*., 2019)
JOURNAL	Climate/Transport	Not specified	Private	Financial(implied)	No	(Melo *et al*., 2020)
JOURNAL	Transport	Various	Various	Not Specified	No	(Moins *et al*., 2020)
JOURNAL	Transport	Not specified	Public	Social	Various	(Mouter, 2018)
JOURNAL	Not specified	Not specified	Not Specified	Not Specified	Variable	(Muller, 2019)
JOURNAL	Energy	Not specified	Not Specified	Not Specified	No	(Neumann, 2021)
JOURNAL	Climate/Water	Not specified	Public	Not Specified	No	(Nordman *et al*., 2018)
JOURNAL	Water	Not specified	Not Specified	Financial(implied)	No	(Oanh *et al*., 2020)
JOURNAL	Water	Not specified	Public	Financial(implied)	No	(Omer *et al*., 2018)
JOURNAL	Climate/Energy	Not specified	Not Specified	Financial(implied)	No	(Onigbajumo *et al*., 2021)
JOURNAL	Transport	Project	Public	Not Specified	Temporal	(Park *et al*., 2018)
JOURNAL	Transport	Not specified	Not Specified	Social	Variable	(Penyalver *et al*., 2018)
JOURNAL	Water	Not specified	Public	Financial(implied)	No	(Peterson *et al*., 2021)
JOURNAL	Transport	Project	Private	Financial(implied)	No	(Polat and Battal, 2021)

JOURNAL	Energy	Not specified	Not Specified	Financial(implied)	No	(Purvins *et al*., 2021)
JOURNAL	Water	Not specified	Not Specified	Financial(implied)	Variable	(Reis and Shortridge, 2021)
JOURNAL	Energy	Not specified	Not Specified	Financial(implied)	No	(Roos, 2021)
SOURCE	**SUBSECTOR**	**FINANCE SCHEME**	**PUBLIC OR PRIVATE PERSPECTIVE**	**TYPE OF DISCOUNT RATE**	**RISK TEMPORALITY OR VARIABILITY**	**Citation**
JOURNAL	Transport	Not specified	Not Specified	Financial(implied)	No	(Sadeghi *et al.,* 2017)
JOURNAL	Energy	Not specified	Public	Financial(implied)	No	(Sahlberg *et al*., 2021)
JOURNAL	Energy/Transport	Not specified	Private	Financial(implied)	No	(Serradilla *et al*., 2017)
JOURNAL	Energy/Transport	Project (implied)	Private	Financial	No	(Shaton and Hervik, 2018)
JOURNAL	Energy	Project	Public	Financial(implied)	No	(Singh *et al*., 2022)
JOURNAL	Climate	Not specified	Public	Social	Temporal, Variable	(Stern, 2018)
JOURNAL	Climate	Not specified	Not Specified	Financial(implied)	No	(Thacker *et al*., 2018)
JOURNAL	Climate	Not specified	Not Specified	Financial	No	(Vasbinder *et al*., 2021)
JOURNAL	Transport	Project (PPP)	Private	Financial(implied)	No	(Vergara-Novoa *et al.,* 2018)
JOURNAL	Climate	Not specified	Not Specified	Financial(implied)	No	(Xi *et al.,* 2019)
JOURNAL	Transport	Project (PPP)	Public	Financial	No	(Yuan and Li, 2018)
JOURNAL	Not specified	Project (PPP)	Not Specified	Not Specified	Variable	(Yurieva *et al*., 2021)
JOURNAL	Energy	Not specified	Not Specified	Financial(implied)	No	(Zhu *et al*., 2017)
JOURNAL	Not specified	Project	Public	Not Specified	Variable	(Zwalf *et al*., 2017)
MLDB	Not specified		MLDB	Both	Various	(Sartori, 2021)
MLDB	Not specified		MLDB	Financial(implied)	No	(Belli *et al*., 1998)
MLDB	Not specified		MLDB	Financial	No	(Asian Development Bank, 2013)
JOURNAL	Energy	Not specified	Public	Financial(implied	No	(Shahriar Haque *et al.*, 2020)
JOURNAL	Transport	Not specified	Public	Social	No	(Andersson *et al*., 2018)
JOURNAL	Transport	Not specified	Public	Financial(implied)	No	(Pimentel *el et al.,* 2021)