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In this article, we describe the objectives, roadmap, and recent progress of academic research with respect to benchmarking the financial performance of privately held infrastructure debt or equity investment, with a focus on the recent development of a new framework to collect data and evaluate such assets.

The current demand for infrastructure investment benchmarks springs from three sources:

- Long-term investors need to formulate investment beliefs before they can make asset allocation decisions. They require benchmarks to evaluate their infrastructure investment managers or strategies, and they also want to evaluate the social and environmental impact of these investments.
- Prudential regulators are required to adequately calibrate long-term infrastructure equity and debt investment within their respective risk-based frameworks, such as Solvency II.
- Policymakers have been calling for a greater use of long-term savings to invest in capital projects that can have a positive impact on economic growth. This matching of long-term capital with infrastructure projects also requires a price discovery mechanism.

These actors have in common the goal of properly framing infrastructure investment so that long-term capital can be adequately deployed in the infrastructure sector.

In recent years, frequent calls have been made in policy to step up data collection efforts with respect to infrastructure investment, but it is often unclear which data should be collected to achieve what end and how to do so. To determine a way forward, we take the following approach: We start from the reasons for the current demand for infrastructure investment benchmarks and list the key questions that such benchmarks should be expected to answer. The answers to these questions (about the risk-adjusted performance, extreme risks, and liability friendliness of infrastructure investment) represent different aspects of the project to create infrastructure investment benchmarks. Unfortunately, as we discuss later, these questions remain very difficult to answer today because of a lack of relevant information.

Hence, we propose a roadmap to develop a definition, valuation, data-collection, and portfolio-construction framework of privately held infrastructure debt and equity cash flows designed to answer these important questions, while respecting the following principles:

- Infrastructure investments must be defined as financial instruments (as opposed to industrial sectors).

- Performance and risk measure must be based on best-in-class models of financial performance.
- The required data must already exist and be sufficiently standard to be observable on a large scale, and they must be limited to a parsimonious list to keep the collection process efficient and realistic.

WHAT ARE THE RELEVANT QUESTIONS?

Privately held infrastructure equity and debt can play a more significant role in institutional investors' portfolios once it is better understood from the point of view of:

- asset allocation,
- prudential regulation, and
- liability-driven investment.

We discuss each dimension in turn in the following sections.

ASSET ALLOCATION: CREATING THE INFRASTRUCTURE BUCKET

For institutional investors, private infrastructure investment can be a performance-seeking allocation to (very) illiquid alternatives. Whether infrastructure has its own bucket or is a sub-bucket in a broader group of assets, the decision to have a specific allocation to infrastructure implies that it has its own unique profile. Documenting the expected risk-adjusted performance of infrastructure investments compared to other public or private assets is therefore necessary to make it a relevant question at the strategic asset allocation level. Likewise, only a proper understanding of realized performance can permit an assessment of the contribution an allocation to infrastructure makes to investment objectives, as well as that of the internal or external infrastructure managers relative to expectations.

Hence, for asset allocation purposes, investors need answers to the following questions:

1. What is the expected return profile of a relevant portfolio of infrastructure investments, and into what investment factors or betas can it be decomposed?
2. What is the current value of the portfolio (and how should realized returns be computed)?
3. What is the reward-to-risk ratio (e.g., the Sharpe ratio) of this portfolio?
4. What is the correlation of realized portfolio returns with that of other relevant groups of assets?

Answering these questions determines, for example, whether there is such a thing as an infrastructure *asset class* that could improve the risk-adjusted outcome of existing asset allocation policies.

PRUDENTIAL REGULATION: DOCUMENTING EXTREME RISKS

Prudential regulation is the second context within which benchmarking infrastructure investments can make an important contribution.

One of the main topics regulators are interested in is *systemic risk* (the risk of collapse of the financial system). As such, they require a clear understanding of the likelihood of very large losses for investors in privately held infrastructure equity or debt in states of the world where other investments also exhibit very large losses.[1] It is on the basis of such assessments that prudential regulation sets *capital buffers* that aim to prevent cascading bankruptcies, as the recent rounds of discussion with the European Insurance and Occupational Pension Authority (EIPOA) about the calibration of the Solvency II Standard Formula to private infrastructure assets illustrate.[2]

Today, privately held infrastructure equity and debt tend to be considered high risk by regulators because they are illiquid, long-term assets with no documented track record. Hence, without adequate calibration of existing prudential regulatory frameworks, institutional investors are less likely to invest in infrastructure due to its high regulatory cost. Moreover, the current treatment of privately held infrastructure is debatable and certainly contradicts the investment beliefs that draw investors to infrastructure in the first place. To improve current calibrations, the following questions require answers:

1. What is the *value-at-risk* (VaR) and *conditional value-at-risk* (cVaR, or expected shortfall[3]) of relevant portfolios of infrastructure equity or debt?
2. What is the maximum drawdown of such reference portfolios?

3. What are the different measures of dependence, including nonlinear correlations (e.g., correlations in very bad states of the world) of the returns of relevant portfolios of infrastructure investments with other financial assets?

Answering these questions will allow better calibrations of prudential frameworks.

LIABILITY-DRIVEN INVESTMENT: UNDERSTANDING THE LIABILITY FRIENDLINESS OF INFRASTRUCTURE

Numerous investors approach infrastructure investment because of its expected ability to help meet liability-hedging objectives. Privately held infrastructure equity and debt can have long tenors and are expected to provide predictable cash flows that are at least in part linked to a domestic price index. For these reasons, infrastructure investments may have the potential to contribute to liability-driven investment objectives, even if they do not correspond to a well-identified asset class from a pure asset allocation perspective, as discussed earlier. Moreover, because most infrastructure investments correspond to a fixed-term concession contract, even the equity stake in infrastructure projects has an end date and therefore a duration. In other words, private infrastructure project equity is potentially *liability friendly*.

In addition to the questions identified previously, specific questions must be answered to document the potential role of infrastructure in a liability-driven investment context. They include the following:

1. What is the effective (option-implied) duration of senior infrastructure debt, taking into account the role of covenants and refinancing in project finance?
2. What is the modified duration of infrastructure equity and quasi-equity?
3. What is the correlation of privately held infrastructure equity returns with the relevant rate of inflation?

Such metrics can play a key role in integrating infrastructure investments in the asset-liability management of institutional investors and are fully part of the objective to benchmark such investments. Indeed, the potential liability-hedging properties of infrastructure investment stand out as some of its most unique and attractive characteristics.

WHY THESE QUESTIONS CANNOT BE ANSWERED TODAY

The questions listed here are important to the future of infrastructure investment by long-term investors, in particular investors with a liability profile and subject to prudential rules, such as insurance firms. However, existing research on private infrastructure investment remains limited. Existing articles exclusively focus on equity investments even though debt instruments provide the most significant source of infrastructure financing. The literature also tends to rely on small samples of Australian data (Newell and Peng [2007]; Bird, Liem, and Thorp [2014]) or samples of cash flows from infrastructure funds (Bird, Liem, and Thorp [2014]), which are more representative of private equity investment strategies (relatively short term and with added leverage) than of the underlying infrastructure assets. Other studies of infrastructure equity performance rely on stock market data (Newell and Peng [2007, 2008]; Bitsch [2012]; Rothballer and Kaserer [2012]), but these have proven ineffective for proxying the performance of unlisted infrastructure investments, as we discuss later.

Hence, the current state of the literature and of investment knowledge does not provide answers to the questions we have defined. Next, we discuss in more depth three key reasons why this is the case: first, the absence of reliable market proxies; second, the substantial limitations of existing private databases and corresponding studies; and third, the tendency in private investment to focus on inadequate investment metrics.

MARKET PROXIES ARE INEFFECTIVE

The first place to look for estimates of expected performance and risk in infrastructure investments is the market for publicly traded securities, including stocks and bonds. A number of thematic infrastructure indexes have been created in recent years that include stocks or bonds corresponding to issuers associated with specific industrial sectors (e.g., transport, energy) and deriving a certain proportion of their income from the same list of infrastructure sectors. As reported before, this approach has so far failed to arrive at meaningful results

(Blanc-Brude [2013]): Listed infrastructure equity and debt indexes tend to exhibit higher risk than broad market indexes (higher maximum drawdown, higher VaR) because they are highly concentrated in a few large constituents and, crucially, do not create any persistent improvement of investors' existing portfolios.

In a recent article, Blanc-Brude, Wilde, and Whittaker [2016] show that the mean-variance frontier of efficient portfolios available to investors allocating to asset classes (stocks, bonds, commodities, etc.) or to factors (value, growth, etc.) is not improved by the addition of a listed infrastructure index, whether provided by an indexer or by directly selecting all stocks corresponding to infrastructure sectors and deriving most of their income from infrastructure.[4] Essentially, focusing on industrial sectors is ineffective because the explanation of the performance of underlying infrastructure investments must be found elsewhere. Indeed, infrastructure investments should not be conceived as real (i.e., tangible) assets since the value of investors' claims is almost entirely determined by the contractual and legal aspects of each infrastructure project (see Blanc-Brude [2013] for a detailed discussion).

Another difficulty with finding listed proxies of privately held infrastructure investments is the small number of stocks and bonds that solely correspond to a pure exposure to the performance of underlying infrastructure equity or debt and not to that of firms active in a given industrial sector whose behavior is less predictable (e.g., some utilities transformed themselves into highly leveraged multimedia empires in the 1990s before collapsing in the dot-com bust). Blanc-Brude, Wilde, and Whittaker [2016] discuss such a rare natural experiment in the form of a portfolio of five stocks listed on the London Stock Exchange: firms that happen to solely buy and hold the equity and quasi-equity of infrastructure projects corresponding almost exclusively to a single type of long-term contract used by governments to delegate investment in public infrastructure, or the so-called *availability payment* model.[5]

In this specific case, a basket of listed equity is shown to exhibit unique characteristics that can be considered to partially proxy the performance profile of equity invested in a basket of several hundred availability payment infrastructure projects, also known as private finance initiatives/public–private partnership projects. This is, however, a small exception, which would not persist if these firms changed investment strategy (e.g., at present, these five firms have very little leverage at the listed entity level), and it is not clear how other forms of underlying infrastructure investments might be proxied in a meaningful manner using public stocks or bonds.

Other approaches involving the use of public market data to benchmark private investments include the *public market equivalent* (PME) of Ljungqvist and Richardson [2003], Kaplan and Schoar [2005], or Phalippou and Gottschalg [2009], which consists of using the cash flows into and out of private investments as if they represented buying and selling a public index. A second version of the PME consists of matching private investments with listed industry betas, deriving the unlevered industry betas using industry averages, and releveraging them using investment-specific information (see Kaplan and Ruback [1995]; Ljungqvist and Richardson [2003]; Phalippou and Zollo [2005] for various applications). However, these approaches imply that the market beta of infrastructure equity and debt is already known, which is at odds with our starting point—that is, the objective to discover its true value.

EXISTING STUDIES OF PRIVATE INVESTMENT DATA ARE TOO LIMITED

Several databases exist that have been used in studies of the performance of private equity investments in infrastructure (see, for instance, Peng and Newell [2007]; Newell, Peng, and De Francesco [2011]). However, such sources of data suffer from major limitations.

First, like listed stocks, the investments are not categorized according to the factors that actually explain volatility and performance in infrastructure (e.g., contracts, risk-sharing mechanisms, revenue support agreements) but instead according to types of private equity (venture capital and leveraged buyouts) and industrial categories. Second, such databases mainly report the cash flows and asset values of private equity infrastructure funds, typically 10-year ventures with high fees and additional fund-level leverage. However, infrastructure private equity funds tend to behave like other private equity funds and aim to exit their investments after a few years.[6] This approach, while perfectly legitimate as an alternative, albeit aggressive, investment strategy, cannot be considered representative of the performance of underlying infrastructure investments.[7]

In fact, it is because infrastructure private equity funds are not representative of such performance that a number of large asset owners have gradually opted to exit such funds, to internalize infrastructure asset management, and to invest directly in underlying assets in order to gain the exposure to the long-term, predictable cash flows they expect to find in infrastructure assets. Thus, there is little to learn about the risk-adjusted performance of portfolios of infrastructure equity from the historical performance of PE infrastructure funds, let alone about the calibration of their prudential treatment or their role in a liability-driven investment context.

On the debt side, the main body of evidence has been collected by rating agencies. These entities have provided numerous ratings for individual issues, both listed and private bonds as well as private loans. However, rating methodologies do not constitute a fully fledged valuation framework; they rank issues relative to each other but never consider the portfolio level, which is the most relevant to the questions identified earlier. Moreover, ratings imply an expected performance but never actually measure it. Individual credit ratings thus cannot be aggregated to create an infrastructure debt benchmark. More quantitative studies conducted by rating agencies document incidents of default and recovery as reported by creditors (see, for instance, Moody's [2014]). These reports are by far the most informative studies conducted today, but they remain insufficient to answer the questions highlighted. First, this information is still categorized by industrial sector, which makes it difficult to quantify the impact of the main drivers of credit risk, such as differences in revenue risk in infrastructure projects. Second, in these studies, the so-called *reduced form* approach to modeling credit risk is preferred: Incidents of default and recovery are observed and assumed to be the result of some exogenous stochastic process, which is considered to be known once a large sample has been obtained. However, sample biases are likely to persist (Blanc-Brude and Ismail [2013] document several such biases in the Moody's [2013] study), and the absence of controls for project-level factors versus external ones (credit and business cycle) gives little predictive power to such results. Moreover, in existing studies, although observations of defaults are quite frequent, losses given default (LGD) reported by different creditors are typically too few to arrive at a full distribution of losses, let alone to control for differences in LGD of different types of infrastructure projects.

Thus, information available from rating agencies about private infrastructure debt, though richer than what exists on the private equity side, is insufficient to answer important questions about the risk-adjusted performance, extreme risk, and effective duration of reference portfolios of private infrastructure debt.

REPORTED FINANCIAL METRICS ARE INADEQUATE

Because most existing information about private investment in infrastructure equity is inherited from the private equity universe, reported performance metrics tend to be limited to net asset values (NAVs) and internal rates of return (IRRs).[8] However, the academic literature on private equity documents shows again and again the tendency of private equity managers to report NAVs opportunistically (see Jenkinson, Sousa, and Stucke [2013] for a recent study). Appraisal-based NAVs also suffer the usual stale pricing issues that lead to smoothing returns and underestimating the volatility of returns. More generally, IRRs as a performance metric are inadequate: The finance literature has long argued that using such constant and deterministic discount rates can be problematic. Standard corporate finance textbook examples (see Brealey and Myers [2014]) show that the use of a single risk-adjusted discount rate for long-lived assets is defective if projects have multiple phases and project risk changes over time as real options are exercised by asset owners.

Indeed, a constant risk premium does not measure risk properly on a period-by-period basis but rather implies that cash flows occurring further in the future are riskier than cash flows occurring earlier (Haley [1984]), which may not be the case, especially given the sequential resolution of uncertainty that characterizes infrastructure projects from construction to operations. The use of constant discount rates then leads to biased calculations of net present value.[9]

When it comes to building investment benchmarks, the use of a constant discount rate is also inadequate for other reasons:

- The IRRs of individual investments cannot be easily used to estimate performance at the portfolio level, as the IRR of a portfolio is not the same as the weighted average IRRs of individual investments.

- IRR-based valuation methodologies cannot be used to identify different sources of return, which requires identifying period returns and decomposing them into systematic and idiosyncratic components. In fact, it is possible to build two streams of cash flows with the same IRR but diametrically opposed market betas.
- In the case of a finite-life investment, using the IRR does not lead to correct duration measure if the risk profile changes over time.

Hence, the metrics currently reported in privately held infrastructure investments are not fit-for-purpose to answer the key questions highlighted earlier, regarding asset allocation, prudential calibrations, and asset-liability management.

Note that this is also a frequent criticism of benchmarks for privately held real estate investments or venture capital. Return smoothing and stale pricing are frequently mentioned issues (see, for example, Geltner, MacGregor, and Schwann [2003]; Florance et al. [2010]). Nevertheless, real estate or venture capital investments can potentially be evaluated using other methods (e.g., hedonic pricing or repeat sales), which can provide a useful cross-validation. Unfortunately, these are mostly unavailable to infrastructure investors given the much lower number of primary and secondary market transactions in this sector.

In what follows, we discuss a way forward to address these issues and progress toward a better understanding of privately held infrastructure investments.

RECENT PROGRESS: THE ROADMAP

Blanc-Brude [2014a] put forward a roadmap for the creation of infrastructure investment benchmarks:

1. Define the relevant financial assets: Improving the benchmarking and regulation of any type of investment first requires well-defined underlying instruments. Today, infrastructure investment is ill defined, and the first step of our roadmap is the creation of unambiguous definitions of what is referred to by financial instruments' long-term investment in infrastructure.
2. Design adequate valuation and risk measurement methodologies: Such methodologies should rely on the rigorous use of asset pricing theory and statistical techniques to derive the necessary input data, while aiming for parsimony and realism in terms of data collection.
3. Determine the data collection requirements: Although ensuring theoretical robustness is paramount to the reliability of performance measurement, a trade-off exists with the requirement to collect real-world data from market participants. In particular, proposed methodologies should aim to minimize the number of inputs in order to limit the number of parameter estimation errors.
4. Standardize performance reporting: The standardization of infrastructure investment data collection allows the emergence of an industry-wide reporting standard, which can be recognized by investors and regulators alike as best practice.
5. Create a database of infrastructure equity and debt cash flows: With the identification of the required data and a standardized reporting/data collection template, a database of infrastructure project cash flows can be built to apply the methodologies in the previous steps.
6. Identify building blocks: A number of risk factors can be expected to systematically explain investment performance in infrastructure projects. Thus, the risk–return profiles of most infrastructure project financing instruments can, for example, be grouped by revenue risk profile on the one hand and lifecycle stage on the other.
7. Define relevant investment strategies: As long-term illiquid assets, a basket of infrastructure projects is not easily or instantly investable. However, the building blocks discussed here can be used to embody different investment strategies that can best achieve investors' long-term objectives.
8. Investment benchmarks: Ultimately, the strategies identified can be used as long-term infrastructure investment benchmarks.

This roadmap integrates the question of data collection upfront, including the requirement to collect only the information that is necessary to implement robust asset pricing and risk models.

Next, we review recent progress on this agenda.

DEFINITIONS OF INFRASTRUCTURE INVESTMENT

Defining infrastructure investments from a financial perspective, the only relevant perspective to build investment benchmarks, is a necessary first step. A decade ago investors, regulators, and policymakers were thinking about infrastructure in terms of industrial sectors, and a coherent definition was nowhere in sight. Indeed, most articles on the subject started with the caveat that there is not a widely agreed-upon definition of infrastructure. Energy and telecoms were equally likely to be included or excluded in definitions, which went from the very narrow (infrastructure equals roads) to the very broad (from rails to rolling stock).

A clear distinction should be made between infrastructure as a matter of public policy, in which case the focus is rightly on industrial functions (water supply, transportation, etc.) and the perspective of financial investors, who may be exposed to completely different risks through investments that provide exactly the same industrial functions (e.g., a real toll road and an availability payment road). In this respect, substantial progress has been made in identifying the characteristics that can be expected to systematically explain the financial performance of infrastructure investments, including, for example, during the 2015 round of industry consultations led by the European Insurance and Occupational Pensions Authority (EIOPA). In particular, the growing consensus around the limited role industrial sector categories play in explaining and predicting performance and the much more significant role played by contracts and by different infrastructure business models, such as merchant or contracted infrastructure or different forms of utility regulation, is encouraging.

A first result has been the identification of limited-recourse project finance as a major and well-defined form of investment structuring for infrastructure projects. Benchmarking project finance debt and equity by broad categories of concession contracts, financial structures, and life-cycle stage is one approach to creating reference portfolios that can be used as benchmarks, including for prudential regulation (Blanc-Brude [2014b]). Although project financing cannot be said to represent all investable infrastructure, it is an ideal type of long-term instrument corresponding solely to the financial performance of individual infrastructure project companies solely dedicated to repaying creditors and investors over the project life cycle. Project finance also presents the advantage of having a clear and widely accepted definition since the Basel II Accords. Thus, benchmarking project finance debt and equity by broad categories of concession contracts, financial structures, and life-cycle stage is one approach to creating reference portfolios that can be used as benchmarks.

In due course, other approaches can complement this first step to integrate other types of underlying infrastructure business models (e.g., RPI-X[10] versus rate of return utility regulation) in a broader benchmarking exercise of privately held infrastructure investments.

ASSET PRICING PRINCIPLES

Once the financial instruments that correspond to infrastructure investment are usefully defined, the second necessary step is to design a performance and risk measurement framework. Of course, measuring the performance of privately held infrastructure debt and equity requires deriving the appropriate discount rates for a given estimate of future cash flows, as for any other financial asset. These instruments, however, are not traded frequently and cannot be expected to be fully spanned by a combination of publicly traded securities. It follows that they are unlikely to have unique prices that all investors concur with at a single point in time. Instead, individual investors can arrive at different valuations of the same infrastructure debt or equity depending on their attitudes toward risk, liquidity, inflation, duration, and so on, and large bid–ask spreads may persist.

It follows that asset pricing models applied to such investments should be able to measure a range of applicable valuations for certain types of infrastructure investments. Indeed, the average realized performance or required returns corresponds to a representative investor that may not reflect many actual investors. Capturing this range of valuations and how it evolves in time is an integral part of benchmarking privately held investments like infrastructure equity or debt. This point highlights the fact that in private markets, cash flow volatility and discount rate volatility must be treated as separate (albeit related) phenomena. In other words, while the pricing of publicly traded securities implicitly combines a cash flow forecast with a required rate of return,[11] valuing privately held investments requires explicitly forecasting cash flow forecast and deriving required discount factors.

Hence, a two-step approach is necessary:

1. First, document the cash flow distributions (debt service and dividends) found in underlying infrastructure investments; and
2. Estimate the relevant (term structure of) discount rates or required rates of returns and their evolution in time.

Understanding Cash Flow Dynamics

To address the fundamental problem of unreliable reported NAVs in private investment discussed earlier, it is essential to develop an independent view of the statistical distribution of cash flows to creditors and asset owners that can serve as the basis for a valuation of privately held infrastructure investments.

Forecasts of future cash flows spanning the entire life of the investment in infrastructure projects are in fact available for both debt and equity investors. Such a base-case scenario of debt service, dividends, and free cash flow is the result of significant due diligence and documentation at the time of investment. Moreover, investors and creditors regularly revise these forecasts, and these new forecasts are documented as well. Base-case and revised dividend and debt service forecasts may, however, vary among investors for comparable projects and substantially deviate from the true statistical expectation of dividends. Still, they are observable.

In two recent articles, Blanc-Brude, Hasan, and Ismail [2014] and Blanc-Brude and Hasan [2015] showed that the combination of base-case scenarios with the well-documented statistical distribution of two types of financial ratios (the debt service cover ratio [DSCR] and the equity service cover ratio [ESCR])[12] is sufficient to derive robust estimates of expected cash flows (in the statistical sense) and their volatility.

Regarding future debt service, Blanc-Brude, Hasan, and Ismail [2014] showed analytically and empirically that knowledge of the distribution of DSCRs over time is sufficient to compute the credit metrics required by a structural credit risk model (e.g., distance to default) and to predict technical[13] and hard defaults in infrastructure debt. They also showed that adequate debt service forecasts should integrate the embedded options available to senior lenders in the event of default because they have a significant impact on the different debt service scenarios. Indeed, infrastructure projects demand large amounts of sunk capital, and most of these funds are typically provided by senior creditors that require significant control rights in the event of a covenant breach. Such contingent control rights (or embedded options) can lead to the restructuring of senior debt and can have a large impact on expected losses and thus on expected and realized performance.

In practice, infrastructure project loans have a *tail* (often described as the number of years beyond the original maturity of the debt during which the firm is still generating an operating income), and failing to value the option to restructure senior debt into the tail is likely to lead to overestimating LGD and VaR and underestimating recovery rates.[14] We show that a standard model of debt restructuring that applies simple, rational rules can determine the potential outcome of predictable credit events and provide a complete estimation of future cash flows to creditors in future states of the world. Likewise, a full distribution of future dividends can be derived from the combination of the expected value and volatility of the ESCR (the tendency to meet the base-case) throughout the life of the investment.

Blanc-Brude and Hasan [2015] showed that documenting ESCRs requires observing realized and base-case dividends, as well as expected and realized project status (e.g., dividend lockup) and milestones (e.g., construction completion). Hence, the statistical distribution (mean and variance) of cash flows to creditors and equity investors at each point in the life of the investment can be modeled by relying on a limited number of data points, as long as basic information about payment priority, covenants, and control rights are also known. Key data points required to properly document these distributions include:

- base-case and revised cash flow forecasts for equity and debt investors,
- actual realized debt service and dividends,
- key financial ratios, in particular the DSCR, and the determinants of their distributions—this requires documenting the factors driving the levels and volatility of these ratios in infrastructure projects, including revenue risk models and other risk-sharing or revenue support mechanisms, financial structure as well as jurisdictions, sectors, and any other factor that may be included in a model of DSCR and ESCR ratios,

- loan covenants and tail to estimate the value of embedded options to senior creditors, and
- expected and realized milestones and status of the firm.

The technical implementation of such cash flow models may vary and depends largely on the quantity and quality of data available. Blanc-Brude, Hasan, and Ismail [2014] and Blanc-Brude and Hasan [2015] provided illustrations of how a limited amount of existing and reasonably standardized data may be used to estimate the expected value and volatility of cash flows to creditors and equity investors in privately held infrastructure investments. Once these data have been collected, future research can also lead to new cash flow model designs.

Understanding Pricing Dynamics

Once the expected value and volatility of cash flows to creditors and investors is known as best as current information allows, the relevant term structure of discount rates needs to be estimated to derive past and forward-looking measures of performance, risk, and liability hedging. Indeed, in light of the perils of using constant discount rates for infrastructure investments as discussed earlier, a term-structure of expected returns (discount factors) must be derived. This is instrumental to:

- measuring current asset values and realized performance and building forward-looking measures of performance for asset allocation,
- deriving the full (conditional) distribution of expected losses and being in a position to predict VaR or LGD levels for prudential regulation, and
- computing duration properly using the correct future discount rates for liability-hedging purposes.

To derive this term structure, two (equivalent) approaches can be used:

1. Factor extraction: For a given future distribution of cash flows (including conditional volatility), a term structure of implied discount rates (required returns) can be derived by observing initial investment values (prices). Ang et al. [2013] used this approach in the case of private equity funds, and Blanc-Brude and Hasan [2015] provided an application to infrastructure project equity using a Kalman filter (other techniques are available depending on the quantity and quality of the data).
2. Risk-neutral valuation: Given expected cash flows to investors, a new shifted distribution of cash flows can be obtained that integrates the (range of) required reward–risk ratio of investors at the time of investment (e.g., basis points per standard deviation of cash flow distribution), which can then be discounted at the relevant risk-free rate. This approach is a standard application of the structural model of credit risk developed by Merton [1974] and is described by Kealhofer [2003]. Blanc-Brude, Hasan, and Ismail [2014] provided an application to private infrastructure debt that integrates the Black and Cox [1976] framework of structural models allowing for debt restructuring.

Both approaches allow derivation of the average required returns of a representative investor but also capture a range of such values, which is the result of the range of prices (investment values) observed in each period and corresponding to similar cash flow processes (same distributions of DSCR or ESCR). Thus, initial investment values, which are observable, must be collected to implement the first approach, whereas risk-neutral pricing requires the collection of credit spreads to compute the required reward per unit of risk of infrastructure creditors.

As project cash flows are realized and observed, the relevant DSCR/ESCR distributions, or buckets, can be determined for each investment, and realized/expected performance can be reassessed, as is the case with public stocks announcing dividends and earnings forecasts. Of course, once individual debt and equity investments can be priced, they can be combined in series of portfolios representing infrastructure, and their performance, extreme risk measures, and liability-hedging properties can be derived as well.

THE NEED FOR COOPERATION

If holding infrastructure debt and equity can give investors access to cash flow processes that have useful characteristics from an asset allocation or a liability-driven investment perspective, our focus should be on identifying and measuring these characteristics and designing the relevant investment strategies.

In this article, we have explained why data collection and investment benchmarking currently are at the top of the policy agenda: A number of important questions about asset allocation, prudential regulation, and asset–liability management need to be answered effectively and efficiently if infrastructure investment is to become a mainstay of long-term investing. Today, these questions are very hard to answer given the current state of investment knowledge, and a comprehensive effort is required to address this issue.

We have defined a simple roadmap that requires agreeing on clear definitions of underlying assets and building robust, state-of-the-art pricing and risk models that avoid the pitfalls of existing practices (e.g., average IRRs) and go beyond the limitations of existing studies and which are designed to deliver the answers needed by investors, regulators, and policymakers. To implement such approaches, cash flow and discount rate models can be built, requiring a parsimonious set of data points that can realistically be collected from investors and lenders. The first four steps of this roadmap are being implemented by academics, investment professionals, and regulators, and the rest of this work can hopefully be done in coming years.

To collect this information and build the datasets that will allow us to answer the key questions identified above, large-scale cooperation is required between investors and creditors, organizations that can collect this information and the regulators that can help make such reporting part of a new standard approach to long-term investment by institutional players.

In 2015, EDHEC began a long process of collection, aggregation, and classification of infrastructure cash flow and investment data at the underlying investment level, starting with infrastructure projects but also compiling data about utilities and other so-called infrastructure investments. Numerous organizations have started supporting this process and now contribute their realized and forecast data. EDHEC is also aggregating data from accounting sources through freedom-of-information requests and other documentary evidence and is now tracking several hundred infrastructure investments going back 20 years or more. Thanks to this new database, the cash flow and pricing models described above can be calibrated as best as current knowledge allows, and the performance of reference portfolios of infrastructure debt and equity investments can be published on a regular basis.

ENDNOTES

[1]In other words, the systemic role of prudential regulation is not to stop investors from taking risk and potentially losing money; rather, it is to understand to what extent all investors face the risk of losing a lot of money simultaneously.

[2]See https://eiopa.europa.eu/regulation-supervision/insurance/investment-in-infrastructure-projects.

[3]cVaR is a so-called *coherent risk measure* and benefits from properties, such as additivity, that make it an adequate measure of portfolio risk.

[4]Rothballer and Kaserer [2012] developed such an approach, which Blanc-Brude, Wilde, and Witthaker [2015] replicate to test the mean-variance spanning properties of listed infrastructure.

[5]In this model, the public sector pays an agreed-upon income to the project firm on a regular basis in exchange for the construction/development, maintenance, and operations of a given infrastructure project, given an agreed-upon output specification and lasting for several decades.

[6]Infrastructure private equity funds are found to be larger and to keep assets for a few years longer than other private equity funds; they are also very concentrated in a few investments. See Blanc-Brude [2013].

[7]Databases of private funds also suffer from the usual sampling and survivorship biases.

[8]The constant discount rate makes an investor's net present value since the date of investment equal zero.

[9]Examples of the inadequacy of IRRs abound in the literature: Phalippou [2008] highlighted that the use of IRRs to measure fund performance allows fund managers to time their cash flows and boost reported performance measures without increasing investors' effective rate of return. Ang and Liu [2004] presented multiple examples of erroneous valuations resulting from the use of a constant discount rate compared to the use of a term structure of time-varying discount rates.

[10]RPI-X, stands for Retail Price Index minus a factor "X" that corresponds to productive efficiency gains that the regulator expects the regulated to be able to achieve in the next relevant period.

[11]This is the essence of the Gordon growth model of stock pricing.

[12]DSCR is the ratio of current debt service to free cash flow or cash flow available for debt service; ESCR is the ratio of realized to base-case dividends, as presented by Blanc-Brude and Hasan [2015].

[13]Default under the Basel II definition.

[14]Conversely, loans with very short tails can see a sharp rise in expected losses toward the end of the loan life, even with very low default probabilities.

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