Strategic Asset Allocation with Unlisted Infrastructure

Better data for sensible results

EDHEC*infra*
building benchmarks
for infrastructure investors

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Noël Amenc is Professor of Finance and Associate Dean for Business Development at EDHEC Business School and CEO of ERI Scientific Beta His concern for bridging the gap between university and industry has led him to pursue a double career in academe and business. Prior to joining EDHEC Business School as founding director of EDHEC-Risk Institute, he was the Director of Research of Misys Asset Management Systems, having previously created and developed a portfolio management software company. He has published numerous articles in finance journals as well as four books on quantitative equity management, portfolio management, performance analysis, and alternative investments. He is a member of the editorial board of the *Journal of Portfolio Management*, associate editor of the *Journal of Alternative Investments*, and member of the advisory board of the *Journal of Index Investing*. He is also a member of the Finance Research Council of the Monetary Authority of Singapore. He was formerly a member of the Consultative Working Group of the European Securities and Markets Authority (ESMA) Financial Innovation Standing Committee and of the Scientific Advisory Council of the AMF (French financial regulatory authority). He holds graduate degrees in economics, finance and management and a PhD in finance.

Frédéric Blanc-Brude is the Director of EDHEC Infrastructure Institute, a dedicated research unit developing a unique body of applied research on infrastructure investment from the perspective of large asset owners. He joined EDHEC-Risk Institute in 2012 after 10 years of private sector experience in the infrastructure finance field, and direct involvement in more than USD6bn of transactions. His research work focuses on asset pricing applied to highly illiquid assets and the stochastic modelling of cash flows in infrastructure projects. He has published papers in economics and finance journals, recently co-authored a book on the valuation of unlisted infrastructure equity and debt investments and is a regular contributor to the press. He is a member of the editorial board of the *Journal of Alternative Investments*. He holds a PhD in Finance (King's College London) and degrees from the London School of Economics, the Sorbonne, and Sciences Po Paris. He is a regular contributor to G20 and WEF working groups on long-term infrastructure investment, has advised the European Insurance and Occupational Pensions Authority (EIOPA) on the prudential treatment of infrastructure investments and also represents EDHEC on the Advisory Board of the Global Infrastructure Facility of the World Bank. EDHEC*infra* was founded in 2016.

Abhishek Gupta is a Senior Research Engineer and the Product Specialist at EDHECinfra. He leads the applied research of unlisted infrastructure indices and advises solutions to prospective clients. He has several years of asset-management industry experience, including working as a quantitative analyst with a private fund manager. He holds a Masters of Science in Financial Engineering from Nanyang Business School and a Bachelor of Technology from the Indian Institute of Technology.

1. Executive Summary

A historical paucity of proper benchmarks means that many investors have to date allocated a disproportionately small proportion of their funds to unlisted infrastructure equity and even less to equivalent debt. This is not surprising – until recently, instead of the essential benchmarks needed for them to assess the risk profile of their investments, they have been forced to make do with appraisal-based or listed infrastructure benchmarks, neither of which are much use in this regard. However, our EDHEC*infra* TICCS-based indices of unlisted infrastructure and debt are now internationally available, changing the game for investors with an interest in this asset class.

Why does this matter? The main reason, as we show in this paper, is that most investors are under-invested in this asset class, and could improve the profile of their portoflio with a larger allocation. The decision on how much to put into unlisted infrastructure has to be made early on in the portfolio design process, and can be difficult to revisit at a later stage given the illiquid nature of unlisted infrastructure assets. As a result, investors can benefit greatly from accessing to the right data in their strategic asset allocation; we show that the EDHEC*infra* indices are currently the best proxies available for this purpose.

In this paper, we show how the traditional indexes used as proxies for unlisted infrastructure fail to represent the qualities of the asset class. Listed infrastructure indices are highly correlated with the wider equity universe – if the asset class behaved in this way, there would be little point in investors buying it as it would not add much in terms of diversification or improving the risk return profile of the portfolio. Appraisal-based indices are correlated with nothing at all, making them singularly useless for the task in hand – their construction gives results that are so "smooth" that volatility is very low and correlations close to zero, which would signal unrealistically high risk-return rewards that are simply unfeasible in the real world. EDHEC*infra*'s indices of unlisted infrastructure, on the other hand, such as the infra300®, represent the characteristics of this asset class well, making them the best available proxy for investors to use.

We also show how investors can carry out a simple asset allocation exercise to calculate the optimal allocation they should be making to unlisted infrastructure based on their individual portfolio needs. Using different optimisation techniques and parameters, and considering different investor profiles, our research signals consistent allocations to infrastructure in the region of 10%, many times current levels. Our indices also offer a granularity that can help portfolio design in a way that broader and less well defined proxies are unlikely to achieve for those seeking to optimise risk-adjusted returns.

In summary, the right mark-to-market indices are now available for investors who believe in this asset class to use as policy benchmarks and assess their optimum allocation to unlisted infrastructure. Investors seeking exposure to this asset class are no longer left guessing when it comes to allocation levels as they effectively have been doing until now. Adding infrastructure can improves the overall risk-adjusted performance of many portfolios, and this can now be done in a fully informed and strategic manner.

2. Introduction

Allocation to unlisted infrastructure in institutional portfolios remains low according to the latest OECD surveys. We argue that this is in part due to the lack of good policy benchmarks for this asset class. This paper addresses the issue of the adequate allocation to unlisted infrastructure in the portfolios of long-term investors. Superior, mark-to-market and granular data on this asset class has only very recently been available to investors, thanks to key advances in data collection and asset pricing technology. We show that, using this data, sensible results can now be obtained that help investors to assess the full benefits of investing in private infrastructure equity and debt.

Academic research in finance has shown time and again that investors' Strategic Asset Allocation (SAA) is a first-order question that determines the majority of the investment process outcome. In a famous study, Brinson et al. (1986) conclude that more than 90% of the variability in portfolio returns over time is explained by asset allocation choices. In other words, in the long term, exposure to systematic (and remunerated) sources of risk (or betas) is what matters the most.

In this context, allocating to alternative asset classes has long been an important avenue for long-term investors to improve the portfolio diversification, as reported in multiple EDHEC*infra* and other surveys. Indeed, investors typically expect exposure to alternative risk premia, notably private markets, to be beneficial, not only in terms of excess returns [1] but also in terms of portfolio risk, since alternative asset classes are not fully exposed to the volatility of liquid markets.

1 - e.g. assuming the efficient capture of an illiquidity premia

Given the importance of SAA in the implementation of efficient long-term diversification, establishing *ex ante* the role of illiquid asset classes such as unlisted infrastructure in the total portfolio at this stage is important because these investment decisions are not easily reversed: transaction costs are high and, in bad times, unlisted infrastructure is almost completely illiquid.

As a result, investors typically intend to hold such assets for substantial periods of time, directly or not, and the decision to include them in the asset mix requires the allocation decision to be based on robust data, i.e. a realistic estimation of the risk/return parameters of unlisted infrastructure equity and debt.

In effect, the choice of data matters at least as much as the choice of asset classes.

For example, in a recent paper, looking at a large sample of pension plans, Broeders and de Haan (2020) find that in the cross-section of pension funds, asset allocation explains on average only 19% of the variation in pension fund returns while benchmark selection dominates and explains 33% of cross-sectional returns.

However, access to reliable infrastructure investment data has long been limited. In a recent review, we showed that both listed proxies and appraisal-based indices paint a highly unrealistic picture of unlisted infrastructure (Amenc et al., 2020). Both can be expected to lead to unusable results when it comes to asset allocation; the former is perfectly correlated with the stock market and the latter is correlated with nothing at all.

Without reliable and representative proxies, investors have been unable to carry out serious quantitative allocation exercises that include the unlisted infrastructure asset class.

They have instead been obliged to use *ad hoc* allocations resting on 'absolute return' benchmarks which, by their very nature, cannot be used in a quantitative allocation exercise. Absolute return benchmarks do not represent the risk-adjusted characteristics of unlisted infrastructure. At best, they constitute a return target that is part of a strategy where the infrastructure investment is designed as an isolated investment sleeve, and one whose weight is determined without reference either to other classes or to the investor's liabilities.

In very concrete terms, when it comes to allocating to unlisted infrastructure today, a very large number of investors still do not use a proper benchmark and they know it, as the 2019 survey of benchmarking practices in the infrastructure sector revealed (Amenc et al., 2019). In this survey, 90% of respondents among the 130 largest asset owners in the world, representing USD10T of AUM, said that they were not satisfied with their infrastructure benchmark.

In the absence of reliable data, allocations to infrastructure have remained conservative. Year after year the OECD survey of large pension funds[2] (OECD, 2019) reports little change in the allocation to unlisted infrastructure equity of large institutions. While some large pension funds make relatively high allocations, the average amongst large institutions is 2% and the average amongst a wider group of pension plans is 1.3%. Allocations to infrastructure debt are much lower at 0.4% of AUM. These figures are consistent with the idea that, lacking reliable data, investors will only apportion a small share of their assets to an illiquid investment that - without an absolute benchmark - they can only hope will have respected their absolute return objectives at maturity .

In a global strategic allocation approach, this marginalisation of infrastructure does not appear to us to be appropriate for the potential risk and return improvement of the investor's portfolio. Indeed, proper policy benchmarks should capture the broad characteristics of individual asset classes and are meant to reflect a long-term risk allocation choice in order to determine the size of each allocation in the total portfolio.

When it comes to unlisted infrastructure, access to the asset class also conditions the choice of benchmark: unlisted infrastructure is not an investable asset class as such. Some institutions invest directly in a handful of assets, others invest via funds, many of which specialise in specific sectors and regions of the world. As a result, one institution might achieve exposure to a combination of contracted infrastructure investments in project vehicles in the transport and renewable energy sectors, while another will focus almost exclusively on regulated infrastructure companies in the network utilities sector.

Different unlisted infrastructure investment strategies and portfolios create different exposures to common risk factors.[3] Strategic allocation to unlisted infrastructure equity or debt can thus involve multiple tilts which can be defined in terms of business risk, industrial activity, geo-economic exposure, and corporate governance (see TICCS®, The Infrastructure Company Classification Standard.4)

A policy benchmark should be precise to represent an investor's preferred opportunity set,

2 - This survey does not refer to the word 'benchmark' once

3 - For example, renewable energy projects are comparatively small and less exposed to the 'size' factor (in effect they are relatively more liquid) than large transport companies like airports. They are also typically much more leveraged than large transport or utilities companies, and thus more exposed, *ceteris paribus*, to an equity risk factor created by gearing of their financial structure. EDHEC*infra* uses a multi-factor model of expected returns to value unlisted infrastructure equity which includes a size risk premium, a leverage risk premium, a profit risk premium, etc. See docs.edhecinfra.com/display/AP

4 - see docs.edhecinfra.com, The Infrastructure Company Classification Standard or TICCS®

possibly combining multiple sub-indices. Access to granular data is therefore important in order to conduct proper asset allocation exercises. The data needed to represent infrastructure investment in the allocation exercise should be granular enough to represent a choice of intentional or *de facto* TICCS tilts made by each investor.

In this paper, we make the case for using EDHEC*infra* data for the purpose of strategic asset allocation. We show that is is better suited to this purpose than any other option available today and provides realistic and robust answers to the questions: which benchmarks should investors use? and how much should they invest in unlisted infrastructure equity and private infrastructure debt?

First, we examine the listed and appraisal-based proxies of unlisted infrastructure sometimes used by investors and often referred to in the literature and test their usability for strategic asset allocation. As mentioned above and in previous papers, listed proxies are highly correlated with stocks because they are fully exposed to equity market risk, while appraisal-based proxies exhibit zero correlation with stocks or bonds because there returns are 'smooth'. We also show that the common practice of unsmoothing returns in appraisal-based indices does not improve the quality of the data. Instead, it makes the outcome of portfolio optimisation a direct function of the choice of unsmoothing techniques and not of the data.

By comparison, a global index of unlisted infrastructure equity, like the infra300® produced by EDHEC*infra* is built to be representative of the investable universe of unlisted infrastructure companies, exhibits no smoothing, a realistic Sharpe ratio and positive but not perfect correlations with other asset classes - unlike contributed indices.

To confirm the superiority of EDHEC*infra* indices, we conduct a simple substitution test in a 60/40 portfolio using either an appraisal-based index or the infra300 and show that only the EDHEC*infra* data leads to asset substitutions that make economic sense.

Another test of the superiority of the EDHEC*infra* data is its ability to capture the differences in risk profiles of different segments of the universe. We also show that using a granular infrastructure benchmark tailored to the sector and business model tilts of individual portfolios improves the Sharpe Ratio of the total portfolio.

Finally, we conduct a normative exercise to examine the role of unlisted infrastructure in a multi-asset class portfolio using forward-looking risk and return data, and compare the results for different investor profiles.

We find that adding infrastructure equity and debt to a multi-asset portfolio can improve the total portfolio Sharpe ratio significantly. Using several optimisation methods[5], our results converge to show that unlisted infrastructure equity and debt always have a role to play in a multi-asset class portfolio combining traditional and alternative asset classes. Typical allocation results to infrastructure are in the 8-10% range, comprising a combination of infrastructure equity and debt, depending on investors' profiles and their focus on performance-seeking or liability-hedging. Investors focusing on hedging their liabilities would allocate a larger part of their total infrastructure allocation to infrastructure debt, which has a higher expected return than investment-grade bonds and can thus reduce their cost of hedging liabilities. Return-seeking investors, on the other hand, would focus more on infrastructure equity, which offers a higher growth potential and an attractive Sharpe ratio.

5 - Return-targeting, risk-targeting and equal risk contribution

These results help documenting the potential role of infrastructure equity and debt investments in investors' portfolios and call for further research on the role of infrastructure in an asset-liability management context.

The rest of this paper is structured as follows: in section 2, we first review the existing work on strategic asset allocation using illiquid alternatives in the research literature. In section 3, we review the different types of proxies of unlisted infrastructure available, and how they behave in-sample, in a simple but fair equity and bond portfolio. We also show the importance of using granular data in this section. Section 4 describes the results of strategic asset allocation exercise with 10 asset classes, using consensus forward-looking risk and return data for traditional and alternative assets and the EDHEC*infra* indices as the proxies of unlisted infrastructure equity and debt. Section 5 concludes and suggests future research.

3. Literature review: long-standing issues with research on illiquid alternatives

In this section, we briefly review the existing research on strategic asset allocation using unlisted and illiquid assets such as private equity, real estate and infrastructure. We note that, much like investors, existing studies suffer from a lack of good data: they mostly use listed or appraisal-based proxies that give unrealistic results, they rely on *ad hoc* 'unsmoothing' techniques, and they add explicit constraints to portfolio optimisations that often become binding and make the results meaningless.

This lack of benchmarks that accurately represent illiquid asset classes including private equity, real estate and infrastructure, often leads to using listed proxies. Numerous studies do this (see for example Bekkers et al. (2009), Ennis and Sebastian (2005), Fischer and Lind-Braucher (2010) ,Idzorek and Armstrong (2009)) and unsurprisingly, all report significant and high correlations between these listed proxies and stocks, ranging from 60% to 90%. These proxies imply a complete lack of diversification benefits from alternative investments. Depending on the choice of listed benchmark, which range from the indices of listed private equity fund managers, to indices of listed companies, these papers also find very different optimal allocations, ranging from 0% to 40%. Because listed proxies are always highly correlated with equities, whether allocation results are very low or very high therefore depends on the choice of the equity proxy, or as we return to below, of arbitrary constraints which have nothing to do with the benchmark data.

In the case of infrastructure, these listed proxies have been shown in peer-reviewed research to be ill-suited to represent unlisted investments: Blanc-Brude et al. (2017) show that none of the 22 listed infrastructure proxies they test can pass a simple mean-variance spanning test, indicating that these indices include assets that are already fully 'spanned' by traditional asset classes, such as stocks and bonds, or by traditional Fama-French factors.

Another group of papers use appraisal-based indices as a proxy for illiquid assets such as Ziobrowski et al. (1997), Waggle and Johnson (2009), Cumming et al. (2013), Finkenzeller et al. (2010). There are two types of weaknesses in this data: it is biased and it is 'smooth'. Biases result from the fact the data is typically contributed by a limited number of asset managers, leading to:

1. Selection biases: The data represents the contributions of managers at each point in time, irrespective of the structure of the investable universe. The data is not consistent in time as constituents enter or leave the universe without any specific control. Fund managers may also choose to report certain data but not others; and,
2. Survivorship bias: Since dead funds or failed investments cease to report before they are terminated, the data for the worst under-performing investments never gets reported and the data tends to be biased towards the winners or best investors, thus not reflecting all potential bad outcomes.

Appraisal-based return data is also 'smooth': the reported NAV of private assets changes very little over time as a result of the approach taken to produce quarterly valuations:

- The cash flows are smooth: A typical appraisal process starts with the previous period's valuation and makes adjustments for the changes in the financial condition of the company or for any significant industry shift. This process is rather expensive and carried out thoroughly at most on an annual frequency which coincides with the financial year end. Valuations for in-between quarters are appraised with limited adjustments and hence, contributing to a time series of quarterly returns which is smoother than it otherwise would be.

- The discount rates are smooth as well: discount rates for private assets are typically derived using a CAPM and some assumed listed proxy for the asset beta, an equity risk premium that is itself smoothed over time, *plus* a fixed *ad hoc* premium for 'lack of marketability' or 'illiquidity'. The choice of risk-free rate, typically also a moving average, is also a typical contributor to the smoothness of discount rates used to value private infrastructure assets. In the end the discount rate of unlisted infrastructure assets is, intentionally or not, practically the same each quarter over long periods of time.[1]

Existing studies acknowledge the issue of the smoothness of returns series, which leads to underestimated risk and correlations with other asset classes, making portfolio optimisation exercises that demand estimates of return co-*variance* highly problematic. As a consequence, these papers all resort to "unsmoothing" the reported returns i.e. removing the serial correlation in the observed returns.

However, other research has shown that the choice of unsmoothing methods and of certain key parameters such as the unsmoothing coefficient, the number of relevant lags, etc. have a significant impact on the outcome of any asset allocation exercise as shown in Marcato and Key (2007). Unsmoothing methods are purely statistical and do not rely on the economic fundamentals that actually drive the variance of unlisted asset prices. While unsmoothing does change the data, it does not improve it. There is no reason to believe that risk measures derived using such techniques have anything to do with the actual risk inherent in the asset class. We return to the process and consequences of unsmoothing in the next section of this paper.

1 - see EDHEC*infra* Webinar replay from 26 May 2020 for a discussion and empirical analysis of the discount rates by unlisted infrastructure funds. Available at EDHEC*infra*.com/webinars

Studies using unsmoothed returns derived from appraisal data find a wide range of allocations to illiquid asset classes, ranging from 20% to 85%.[2] These very high and unrealistic allocation results are due to the artificially low correlations with other asset class, which typically survive the unsmoothing. The lower results are driven by the third issue found in existing studies: binding constraints set explicitly in the optimisation process.

Due to the inadequacy of the data, existing research adds arbitrary constraints on illiquid asset classes to the portfolio optimisation, which tend to become binding restrictions of the allocation results. Ennis and Sebastian (2005), for example, specify an explicit allocation constraint of 10% on real estate which becomes binding in most of their tested scenarios. Similarly, Karavas (2000) add constraints on stocks and bonds and then suggest a 10-20% optimal allocation to both private equity and hedge funds. Waggle and Johnson (2009) also define permissible allocation ranges for all asset classes, and still report that real estate takes up the maximum 20% allowed under all optimisation scenarios.

In conclusion, existing research has not been able to shed much light on the optimal allocation to unlisted infrastructure or other highly illiquid alternatives. This is because existing results are mostly driven by choices of unsmoothing techniques and choices of portfolio constraints instead of the ability of the benchmark data to capture the risk-return profile of the asset class. Having noted these issues, to which we will return below, we now compare three available proxies of the unlisted infrastructure equity asset class.

2 - which would have been even higher were it not for the unsmoothing.

4. Finding the best proxy of the Unlisted Infrastructure Asset Class

In this section, we examine three types of data that investors and consultants might try to use to conduct an SAA exercise including unlisted infrastructure equity. We first review the characteristics of this data, then conduct a simple 60/40 in-sample substitution test and finally examine the differences between granular indices of unlisted infrastructure investments.

4.1 Three proxies of unlisted infrastructure equity

We consider in some detail the differences between listed, appraisal-based and marked-to-market (EDHEC*infra*) unlisted infrastructure equity index data. This is an empirical exercise based on the historical returns of these proxy indices and used to assess their risk and return profiles and their correlations with stocks and bonds.

4.1.1 A listed proxy

For a listed infrastructure proxy, we use the S&P Global Infrastructure index for the 15-year period from January 2005 to December 2019 and include 75 constituents in 17 countries.

We find that the performance of listed infrastructure is very close to that of other listed equity indices in terms of risk and returns, and also that it is not representative of the unlisted universe.

Table 1 shows the risk-return profile of this index and other popular public equity indices and styles. Since the constituents of the listed infrastructure index are primarily located in developed countries, we use the MSCI developed market indices to represent the various segments of the equity market. As expected, we see that the risk and return profiles of the listed infrastructure and broad-market equity indices are very close: their historical annualised average return is 8.9% and 8.7%, respectively, and their annualised volatility is 14.6% and 14.7%, respectively. Thus, these two indices could largely substitute one another in a portfolio.

Indeed, the listed infrastructure index is also highly correlated with the equities index. This high correlation originates, in part, from the overlap of their constituents. Indeed, we find a 46% overlap by number of constituents between the S&P global listed infrastructure index and S&P global 1200, representing a 64% overlap by market capitalisation.

Table 2 shows the correlation of listed infrastructure indeices with similar equity and sub-equity indices or styles, as well as the market beta[1] of each of these segments or factor. We see that the listed infrastructure index has an 80% total return correlation with global equity as well as with thematic factor/sector indices. Likewise, the market beta of the listed infrastructure index is similar to that of thematic factor and sector indices. Since these are not considered to be separate asset classes, the listed infrastructure index cannot be considered one either.

We also note that the listed infrastructure index is highly concentrated in a few sectors and is not representative of the unlisted infrastructure market. Table 3 shows the allocation by sectors of this index compared to the unlisted infrastructure universe documented by EDHEC*infra* for the 25 most active unlisted infrastructure

1 - Beta is calculated as the coefficient of the linear regression between the monthly returns of the index and the equities index (market index).

Table 1: Performance of listed infrastructure proxy and various developed equity indices and sub-indices or styles

Asset class	Return	Risk	Sharpe ratio
Listed infra	8.9%	14.6%	0.61
Equities	8.7%	14.7%	0.59
Technology	13.5%	17.1%	0.79
Industrials	9.6%	17.1%	0.56
Quality	11.0%	13.1%	0.84
Min Volatility	9.1%	10.6%	0.86
Value	7.6%	15.1%	0.50
Growth	9.9%	14.9%	0.67

Source: Datastream. Listed infra (S&P Global Infra), Equities (MSCI Dev World), Technology (MSCI World IT), Industrials (MSCI World Industrials), Value (MSCI World Value), Growth (MSCI World Growth), Quality (MSCI World Quality), Min Volatility (MSCI World Min Volatility). Monthly returns in USD over 15-year period: Jan 2005 to Dec 2019. Return is computed as the compounded annual total return of the respective index proxies. Risk is calculated as the annualised standard deviation of the index proxies. Sharpe Ratio is the ratio of the return and risk figures, assuming a 0% risk-free rate.

Table 2: Correlations and market beta of listed infra with equity indices

Asset class	Correlation with listed infra	Market Beta (CAPM)
Listed infra	1.00***	0.87
Equities	0.88***	1.00
Technology	0.71***	1.04
Industrials	0.83***	1.12
Quality	0.85***	0.86
Min Volatility	0.89***	0.64
Value	0.88***	1.00
Growth	0.86***	0.99

Source: Datastream: Listed infra (S&P Global Infra), Equities (MSCI Dev World), Technology (MSCI World IT), Industrials (MSCI World Industrials), Value (MSCI World Value), Growth (MSCI World Growth), Quality (MSCI World Quality), Min Volatility (MSCI World Min Volatility). Monthly returns in USD over 15 years period: 2005 Q1 to 2019 Q4. *** Significant at the 1% level.

national markets. The listed index is concentrated in the energy, transport and the utilities sectors with power companies taking up almost half of the index and are more than 200% overweight as compared to the unlisted universe. In fact, because numerous infrastructure companies such as project finance vehicles used to create wind farms, road or power plant companies are never listed, listed proxies are unable to offer the relevant coverage of the unlisted infrastructure universe.

Furthermore, coverage is hampered by the lack of clear definition for the infrastructure companies used in the listed indices. A number of firms found in the S&P listed infrastructure index do not in fact have a valid TICCS® classification[2] as shown in table 2 in the case of 'Oil & Gas Equipment and Services' which represents close to 20% of the index. This is an endemic problem in listed infrastructure indies. *Amenc et al (2017)* show that passive (index-based) and active (via mutual funds) products that feature the word "infrastructure" in their name and marketing documentation have similar or worse characteristics than the broad public equity market and typically include stocks that are not infrastructure companies by any stretch of the imagination (the authors call this phenomenon 'fake infra'). Thus, listed infrastructure indices are fully exposed to equity risk and can only be considered a segment or style within public equities and not at all a proxy of the unlisted infrastructure asset class.

Indeed, the performance of all listed equities is dominated by their exposure to the market risk. Even if this benchmark only contained listed companies that were genuinely involved in infrastructure-related activities, the fact that they are listed - and that therefore, the possibility exists of a perfect arbitrage within the equity market - means that the idiosyncratic characteristics of these stocks must disappear. It follows that listed infrastructure indices can only capture the risk premium associated with the equity market risk, rather than the risk that is specific to the variability and the duration of the cash flows of the infrastructure companies which, in fact, is the primary focus of the investors in this asset class.

2 - see docs.EDHEC*infra*.com, The Infrastructure Company Classification Standard

Table 3: S&P Global Listed Infrastructure - sector weights vs. the unlisted universe

	S&P Global Listed Infra	Over/under-weight	Unlisted Infrastructure Universe
Power	46.70%	211%	15%
Oil and Gas Equipment and Services	19.30%	N/A	0%
Gas, Water Multi-utilities	19.70%	-38%	32%
Transport	13.10%	-38%	21%
Other	1.20%	-96%	Renewables:18% Social infrastructure:4% Data Infrastructure:7% Environmental Services:2%

Source: Datastream, EDHEC*infra*, April 2020

If the nature of infrastructure investment really was as listed infrastructure indices suggest it is, then there would not be much point in investors seeking a exposure to 'infrastructure' at all since they are already exposed to the same risk-return profile through their listed equity position.

De facto, we can conclude from this analysis that listed infrastructure indices do not constitute a policy benchmark that is representative of a distinct infrastructure class and as such have no relevance to carrying out an allocation exercise.

Next, we discuss the characteristics of appraisal-based benchmarks and whether they are better suited to represent the unlisted infrastructure asset class when it comes to the process of strategic asset allocation.

4.1.2 An appraisal-based proxy

The appraisal-based proxy used is the Preqin Infrastructure index, which is a quarterly index only available from Q2 2008. We use the index over the period Q2 2008 to Q4 2019.

In this section, we describe the characteristics of appraisal-based indices of unlisted infrastructure returns. These indices are typically computed by aggregating the cash flows and Net Asset Values (NAVs) of reported by unlisted infrastructure funds asset managers, either at the fund or asset level. Two examples of such datasets are the Preqin unlisted infrastructure index, a fund-level, post-fees index of unlisted infrastructure investments reported by a selection of managers, and the MSCI Unlisted Infrastructure Index which is an asset-level index.

In what follows, we look at the Preqin Infrastructure index: the history of this index is limited and returns are only available from Q2 2008 Q2 in USD. Table 4 shows the raw risk-return profiles of the Preqin index compared with equities (Russell 3000) and bonds (Bloomberg Barclays Aggregate).

We see that the Preqin Infrastructure index reports high returns per unit of risk. The very low return volatility, which is driven by the 'smooth' valuations referred to earlier, apparently leads to a very attractive and unrealistically well-rewarded asset class with a Sharpe Ratio of 1.15; in fact for the Q3 2009 to Q4 2019 period, on a 10-year annualised basis, the Sharpe ratio of this index is higher than 3!

The presence of return smoothing can be tested by calculating the serial correlation of the returns, i.e., measuring the correlation of asset returns over some period with the same returns with a given time lag. In principle and empirically, returns based on mark-to-market valuations are independent in time and show very little serial correlation. A positive correlation would indicate that the reported returns are partially explained by the returns of the previous periods.

Table 5 shows the first-order autocorrelation in the quarterly returns of the Preqin index, which exhibits close to 40% autocorrelation in quarterly returns. This serial correlation is also statistically significant at the 5% significance level

Table 4: Comparison of Preqin infrastructure index with Bonds and Stocks (USD returns)

Asset class	Return	Risk	Sharpe ratio
Preqin infra index	8.0%	7.0%	1.15
Equities	11.7%	16.5%	0.71
Bonds	2.7%	5.7%	0.48

Sources: Preqin, Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate). Period: Q2 2008 – Q4 2019, All quarterly total returns in USD. Preqin data is net of fees.

as indicated by the low p-value of the Box-Ljung test[3]. Conversely, equities and bond market returns exhibit no return autocorrelation at all (the BL test shows that the estimated correlation coefficient is not statistically different from zero), which is the standard result.

Such smooth valuations and returns mean that the variance and, therefore, the co-variance of returns in the Preqin index are underestimated. In the context of deriving meaningful asset allocation implications from the benchmark data, this is material and highly problematic.

Indeed, Table 6 shows the correlations of this index with the same equities and bond indices. We see that the Preqin index exhibits zero correlations with both the asset classes (the correlation coefficient is not statistically different from zero). If true, this would mean that unlisted infrastructure fund investments do not exhibit any common characteristics with either equities or bonds. This is surprising and as Amenc et al (2020) have argued clearly not realistic. In practice, the smoothness of the returns is responsible for this lack of correlation.

In conclusion, we note that, while appraisal-based indices are made of investments in actual unlisted infrastructure companies, their computation methodology makes it difficult to estimate risk. Unlike listed proxies, which showed perfect correlation with markets, this data exhibits zero correlation with other asset classes and has a high Sharpe ratio, simply because it does not exhibit realistic volatility. *De facto*, calculating volatilities and correlations using indices of this kind is totally unhelpful from both an economic and statistical viewpoint.

3 - Box-Ljung test determines whether a series of observations over time are random and independent. A significant p-value in this test rejects the null hypothesis that the time series isn't autocorrelated.

Ultimately, this artificial risk dominance means that in a portfolio optimisation context and without constraints, it should take over the entire portfolio... Naturally, investors who are conscious of the limitations of this type of data will give up on carrying out an allocation exercise. They are likely to simply adopt a very conservative *ad-hoc* approach by assigning a modest amount of money to unlisted infrastructure investments in an arbitrary way without really worrying about the impact of this sleeve on the rest of the portfolio, since the value of the segregated infrastructure sleeve is so limited that its impact on the risk of the portfolio is itself fairly insignificant.

Next, we review the third proxy: a bottom-up, marked-to-market index of unlisted infrastructure equity.

4.1.3 A marked-to-market index

The third proxy is the infra300, a marked-to-market index produced by EDHEC*infra*. We focus on the same time period than the one available for the Preqin index to ensure a fair comparison between the two unlisted proxies. The infra300 index is available from 2000 onwards.

Building a representative and fair index

The infra300 is the result of a methodology designed to address the two main issues observed in appraisal-based indices i.e., representativity and fair market value.

To build a representative view of the investable universe, the EDHEC*infra* methodology follows a scientific approach to identify the relevant

Table 5: Serial Correlation (smoothing) in Preqin Infrastructure Index Returns

Metric	Preqin Index	Equities	Bonds
Autocorrelation	0.39***	0.0862	-0.0637
Box-Ljung test (p-value)	0.006	0.542	0.652

Sources: Preqin, Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate). Period: 2008 Q2 – 2019 Q4, all returns in USD. *** Significant at the 5% level

Table 6: Quarterly Return Correlations between Preqin Infrastructure Index, Bonds and Stocks

	Preqin Index	Equities	Bonds
Preqin index	1.00		
Equities	0.01	1.00	
Bonds	-0.12	0.14	1.00

Sources: Preqin, Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate) . Period: 2008 Q2 – 2019 Q4. all returns in USD.

markets and pick the relevant constituents of a broad-market index.

Data is collected and structured using TICCS®, an objective and consensus taxonomy of infrastructure companies that is also an industry standard. The investable universe is defined as the 25 most active markets globally and includes more than 5,500 unlisted infrastructure companies, all of which have been uniquely identified and categorised using TICCS. From this universe, a representative sample of more than 600 companies over the past 20 years is created. Each of these companies is studied in detail by a team of financial analysts, who collect, aggregate and validate the relevent financials, understand their history and prospects and produce quarterly updated revenue, cash flows and dividend forecasts on the basis of sector and company-specific information.

With this approach, the EDHEC*infra* data avoids the main biases in appraisal-based indices:

1) It avoids selection bias since the constituents of the broad-market index are sampled from a well-defined and highly relevant population of investments and based on the structure of the market at each point in time e.g. over time the types of unlisted infrastructure companies available to investors have changed.
2) We also avoid survivorship bias since there is no backfilling of index constituents, instead we 'fill forward' as new infrastructure companies become investable or have to leave the index because they fail or reach the end of their lives. This is well illustrated by the number of adverse events in the history of the sampled universe: in the 630+ companies tracked in the EDHEC*infra* broad market universe, over the past 20 years we observe more then 150 events of default or dividend lock-up, several dozen events of bankruptcy and more than a dozen events of termination by the public sector. These defaults and bankruptcies are typically found in companies that are exposed to the economy because they have a 'merchant' business model (e.g. after a recession) or because of structural shifts affecting an entire industrial sector (e.g. electricity market prices permanently lower than the marginal production cost of older power plants).

Along with using better data, these indices also follow a consistent valuation methodology to estimate the fair market values of infrastructure companies.

However, pricing hundreds of unlisted companies at the end of each quarter in a very illiquid market where few transactions occur in each quarter requires an innovative and robust approach. In private asset classes like real estate, it is possible to use comparable transactions to assess the evolution of the market of specific types of property. In the unlisted infrastructure space there are no such 'comps': infrastructure companies are very different from one another and it is hard enough to find an airport that resembles the one that has to be priced, let alone

one that has traded in the past three months. To use direct 'comps' in infrastructure valuations, as one does in real estate, one would sometimes need to have more transaction data than there are comparable assets in the world.

Still, this does not mean that the fair value of infrastructure companies is not driven by common factors. Simply because each company is quite different from the next, this does not mean that all drivers of its market value are purely determined by idiosyncratic features.

This is very fundamental point, which is often lost in a more 'naive' understanding of the value of private assets: the belief that they are somehow "100% idiosyncratic" and can be benchmarked using an absolute rate of return. This is, of course, wrong. In fact, the impact of the Covid-19 pandemic on infrastructure businesses, which we discuss below, reminded many investors that these companies do not exist in a vacuum and are exposed to a range of risks.

Instead, EDHEC*infra* approaches the valuation of these illiquid, unique and heterogeneous infrastructure companies from the point of view of modern finance: while we cannot use comparable transactions to estimate their latest valuation ratios, it is possible to reduce the number of dimensions of the problem and to estimate the price of such assets for the average buyer or seller by pricing the few systematic risk factors that are found in each transaction, irrespective of their idiosyncratic characteristics.

In other words, while infrastructure companies are different from each other, they belong to a category of assets that have common valuation factors, and these factors are what drives the formation of prices in the market.

At the end of each quarter, the fair market value of any unlisted infrastructure equity investment is a function of three components: a future stream of dividends (cash flows), the term structure of risk free rates at the relevant horizon (e.g. some investment have payoffs 20 years into the future, others 35 years, etc.) and a risk premia.

Given a stream of expected cash flows (which can come from the asset owner), and a term structure of rates (which can be built using the yield of risk-free bonds at the relevant horizons), the fair value of illiquid infrastructure assets requires measuring an equity risk premia for each of the firms.

Next, the fair risk premia applicable to any infrastructure investment at one point in time can be estimated in three steps. First, using the a series of secondary market transaction prices, an expected return can be inferred and, using the risk-free curve, a deal risk premia can be extracted for each transaction.

For example, if we observe a secondary market transaction for the equity of infrastructure company j, we have:

$$P_j = \sum_{t=1}^{T} \frac{D_{j,t}}{(1 + r_t + \gamma_j)^t}$$

where T is the investment's expected life, r_t is the risk-free rate at each point in time until date T and γ is the deal's risk premia.

Using a numerical solver, the value of γ_j is obtained and represents the equity risk premia required by investors in transaction j, given expected cash flows D_j, the term structure of rates r_t with $t = 1 \ldots T$, in the relevant country at the time of the transaction and the price paid P_j.

Second, each observation of a new γ_j is used to calibrate a risk factor model of the risk premia. We can write:

$$\gamma_j = \beta_1 \times \lambda_1 + \beta_2 \times \lambda_2 \ldots + \omega = \sum_{k=1}^{K} \beta_{j,k} \times \lambda_k + \omega$$

where β_k represents the exposure of company j to risk factor k at the time of the transaction and λ_k is the price or risk premia associated with factor k at that time and ω is a stochastic process representing the idiosyncratic 'noise' in transaction prices.

The risk factor exposures or β_k of each company are based on observable firm financials (e.g. size, leverage, etc. we return to this below) or other observable characteristics and the price of each risk factor are re-estimated each time a new transaction takes place.

Before assessing each transaction, the set of risk factor prices obtained from the previous transaction is used as the prior value for each λ_k and the value of each risk factor price is then updated using the new information (formally, this is known as Bayesian inference and technically as a Kalman filter).

If the model provides a robust explanation of the variance of observed risk premia in actual secondary market transactions, then it can be said that the K factors provide a good model of the systematic price of risk in these transactions. To obtain a quarterly factor price for each risk factor, the average price implied by each deal of the quarter is used.

Finally, once the price of each risk factor is known at the end of each quarter, all that remains is to multiply the risk factor exposure of any infrastructure company for which we seek a fair equity value by the price of each risk factor, so that the estimated equity risk premia $\widehat{\gamma}_i$ of company i is given by:

$$\widehat{\gamma}_i = \sum_{k=1}^{K} \beta_{i,k} \times \widehat{\lambda}_k$$

where $\widehat{\lambda}_k$ is the estimated price of risk factor k at the time of valuation.

Each firm-specific market risk premia estimated at the end of each quarter is then combined with the term structure of risk-free rate that matches the horizon of the investment and therefore its duration, in the country and on the date of the valuation.

Hence, the quarterly valuations of asset i is obtained by discounting each future dividend at time t at the marked-to-market discount factor $(1 + r_t + \widehat{\gamma}_i)^t$. This process is summarised in figure 1.

Several years of research into the determinants of expected returns in unlisted infrastructure companies have led to the selection of several key factors that are found to explain observed transaction prices and their implied expected returns. We have established that the most relevant, robust and persistent risk factors that explain transaction prices in unlisted infrastructure transactions are:

1. Leverage (Senior liabilities over total assets)
2. Size or total assets
3. Profitability (Return on Assets before tax)
4. Investment (Capex over total assets)
5. Country risk (Term spread])
6. A range of control variables including business model and industrial activities according to the TICCS® taxonomy of infrastructure companies.

Note that these factors are in line with fundamental concepts in asset pricing and corporate finance. For example, higher leverage should increase the cost of equity as per the Modigliani and Miller theorem, and the size, profits and investment are well established risk factors in modern equity valuation since Fama and French.

It is also important to note that such an approach rigorously follows the IFRS 13 guidance on measuring fair value in unlisted investments, from focusing on principal markets, to using contemporaneous market inputs and, crucially, calibrating valuations to market inputs at the time of valuation.

These results are also robust. For the calibration of the risk premia of infra300 constituents we process the data for more than 1,000 transactions since Q1 2000 and we find that:

1. The residuals of the risk premia model $\hat{\gamma}_j - \gamma_j$ have zero mean and a symmetrical distribution i.e. white noise, indicating that any part of the risk premia observed in secondary market transactions prices that is not explained by our risk factors model is the idiosyncratic part. This is relevant only to individual buyers and sellers and not a driver of the average market price;
2. Out-of-sample (before the fact), the average pricing error of actual secondary market prices is in the +/- 5% range.

Thus, using a DCF-based valuation approach for hundreds of unlisted infrastructure companies implemented at the end of each quarter, total return indices of unlisted infrastructure equity investments can be computed.

The infra300 index tracks the performance of 300 infrastructure companies and approximately USD200bn of market capitalisation worldwide (Bloomberg® ticker: infra300). Each quarter, EDHEC*infra* computes several hundred indices of performance and risks of its broad market universe that correspond to the different TICCS® segments of the market (accessible at indices.edhecinfra.com).

It is important to note that such an approach rigorously follows the IFRS 13 guidance on measuring fair value in unlisted investments, from focusing on principal markets to using contemporaneous market inputs and, crucially, calibrating valuations to market inputs at the time of valuation.

Characteristics of the infra300

As well as producing a representative index relative to the different segments of the universe, we avoid the other major issues of contributed indices that rely on appraisals:

- There is no more smoothing in the returns and a proper measurement of the variance of returns is possible. This is confirmed by the absence of serial correlation in the infra300 returns compared to the often used Preqin (appraisal-based) unlisted infrastructure index as shown in table 7. No unsmoothing of the infra300 is necessary.
- The absence of serial correlation means that the covariances of returns between the infra300 and other asset classes can be used directly. Table 8 shows the correlations of the infra300 index returns with those of equities and bonds. We use the same proxies for equities and bonds as in section 4.1.2, and also restrict the data to the same time period of 2008 Q2 to 2019 Q4 (the longest available for the Preqin index). We find that infra300 index has an 18% and 31% correlation with equities and bonds respectively. This is an expected result since EDHEC*infra* indices, just like the equity or bond indices, are also computed using the contemporaneous market inputs, such as interest rates, FX rates and secondary market transactions. These correlations are significant but suggest a genuine diversification potential.
- We estimate much more realistic risk and risk-adjusted returns levels as shown in table 9. We note that this proxy of unlisted infrastructure has a risk-adjusted return of 0.77, which is attractive but realistic when compared to the Shape ratios implied by smooth appraisal data.

Overall, the infra300 represents a good choice of proxy for the unlisted infrastructure asset class. It is designed to be representative of the investable infrastructure market, does not have any of the data biases or smooth returns seen in appraisal-based indices, and it captures risks and corre-

Figure 1: Expected returns modelling process for unlisted infrastructure equity

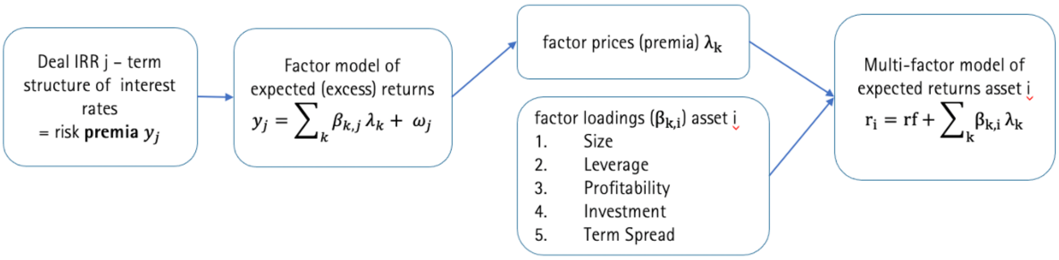


Table 7: Absence of serial Correlation in the infra300 Index Returns

Metric	Infra300 (Local)	Infra300	Equities	Bonds
Autocorrelation	0.0201	0.1887	0.0862	-0.0637
Box-Ljung test (p-value)	0.887	0.182	0.542	0.652

Sources: EDHEC*infra* (infra300 index), Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate). Period: 2008 Q2 – 2019 Q4. all returns in USD unless indicated.

Table 8: Return Correlations between EDHEC*infra* Index (infra300®), Bonds and Stocks

	Infra300 Index	Equities	Bonds
Infra300 index	1.00		
Equities	0.18	1.00	
Bonds	0.31	0.14	1.00

Sources: EDHEC*infra* (infra300 index), Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate). Period: 2008 Q2 – 2019 Q4. all returns in USD.

lations thanks to it marked-to-market methodology.

Next, to further distinguish between the different sources of data, we conduct a supplementary test of the quality of appraisal-based index data (Preqin) compared with the infra300 index in a simplified allocation exercise.

4.2 An in-sample substitution test with a 60/40 portfolio

In this section, we test the substitution behaviour of unlisted infrastructure proxies in a simple portfolio of stocks and bonds to assess the reliability of the data in an asset allocation framework.

We use a classic 60/40 (stocks/bonds) portfolio as the baseline. As in previous sections, we use the Russell 3000 index to proxy equities and the Bloomberg Barclays Aggregate Bonds index for bonds for the period Q2 2008 to Q4 2019 (longest period available for Preqin data).

We choose to ignore the listed infrastructure proxy in this exercise as we already know that is it fully 'spanned' by stocks and bonds, which makes studying the substitution behaviour of the proxy with stocks and bonds quite pointless.

Thus, we consider adding either the appraisal-based index from Preqin or the infra300 index4 from EDHEC*infra* to the 60/40 portfolio and examine the substitution with stocks and bonds in an unconstrained return-targeting optimisation exercise. The objective is set to minimise portfolio risk with a return target greater than or equal to that of the 60/40 portfolio or 7.8%, based on historical returns. The results are shown in table 10.

As expected, the Preqin index tends to dominate due to its quasi-zero correlation with other asset classes and very high Sharpe ratio, which are both of course the result of smoothing. Hence, the allocation to infrastructure is very large (close to 70%) which is unrealistic for most investors but also typical of some of the results found the research literature described above. Crucially, the substitution behaviour of the Preqin index is

4 - Infra300 index is presented as net of return for a fair comparison with the Preqin index. It assumes a blended investment cost of 2.5% based on the historical trends of management fees and performance fees in infrastructure funds.

Table 9: Comparison of EDHEC*infra* index with Bonds and Stocks (USD returns)

Asset class	Return	Risk	Sharpe ratio
Infra300®	12.4%	16.1%	0.77
Equities	11.7%	16.5%	0.71
Bonds	2.7%	5.7%	0.48

Sources: EDHEC*infra* (infra300 index), Datastream: Equities (Russell 3000), Bonds (Bloomberg Barclays Aggregate). Period: 2008 Q2 – 2019 Q4, all returns in USD. EDHEC*infra* data is gross of fees.

Table 10: Substitution with infrastructure in 60/40 portfolio with Preqin or EDHEC*infra* proxies

Portfolio	Optimal weights			Portfolio return	Portfolio volatility
	Infra	Equity	Bonds		
60/40 portfolio w/o infra	NA	60.0%	40.0%	7.8%	10.5%
Substitution with Preqin index	68.9%	18.6%	12.5%	7.8%	5.8%
Substitution with net infra300 index*	28.1%	37.9%	34.1%	7.8%	9.1%

Sources: EDHEC*infra* (infra300 index), Preqin, Datastream: Equity (Russell 3000), Bonds (Bloomberg Barclays Aggregate) . Period: 2008 Q2 – 2019 Q4. Infra300 index returns are gross of fees. Preqin index returns are net of fees. *Net infra300 index assumes a blended fee of 2.5% p.a.

inconsistent: it replaces both equities and bonds in the 60/40 portfolio.

The infra300 index, in sharp contrast, shows a consistent substitution behaviour by replacing primarily equities in the 60/40 portfolio. The optimal allocation to infrastructure equity is also much more reasonable considering that this is an unconstrained optimisation exercise with only one alternative asset class and no penalisation of this for its illiquidity. We note that while the infra300 index is volatile and correlated with other asset classes, it still reduced portfolio risk significantly from 10.5% to 9.1%, highlighting the diversification benefits captured by the index.

Again, this is 60/40 substitution test is only meant to stress the importance of using the right data and benchmark. Of course, it has important limitations including:

- The use of in-sample data over a relatively limited period of time using quarterly returns.
- A simple return-targeting optimisation approach, without constraints on diversification or liquidity, assuming only three asset classes: equities, bonds and infrastructure.
- The exceptional period for infrastructure valuations which increased significantly after 2008 as the asset class became more accessible and popular but also stopped increasing so markedly after 2016 (see Blanc-Brude and Tran, 2019). Hence forward-looking unlisted infrastructure returns cannot be derived directly from past returns. The appraisal-based data is backward looking by design. We note that the EDHEC*infra* methodology is based-on estimating forward-looking (expected) returns at each point in time and then to compute realised returns. We return to using forward-looking returns later in the paper.

Despite these limitations, this approach highlights the advantage of carrying out a fair comparison between the Preqin and infra300 indices, notably because it reveals that the unrealistic, backward-looking aspect, which leads to very smooth returns due to the valuation practices of the funds that contribute to these types of indices, makes it impossible to use these data series in an allocation exercise.

Faced with this criticism, as we noted above, it can be tempting to unsmooth appraisal-based returns to try and recreate some variance in the return series. We explore this option in the next section.

4.3 Unsmoothing the Preqin index?

In this section, we show that unsmoothing appraisal-based data does not improve the results obtained in an portfolio optimisation exercise.

Unsmoothing consists of removing the serial correlation found in the return series: popular unsmoothing approaches include autoregressive filtering (Geltner), equity volatility method

(Fisher, Geltner & Webb), and market states method (Chaplin).

These techniques rest on the following intuition: observed returns are weighted averages of current and past economic returns, which are otherwise unobservable. By estimating these weights, one obtains an "unsmoothed" version of the returns which should better reflect their variance as well. However, they rely on several assumptions: adjusted and unadjusted series have the same mean, the model holds over time (stationarity), and a number of parameters, including the number of relevant lags, are known ex ante. Changing these parameters may lead to very different risk or correlation estimates. As a result, an allocation decision obtained using risk estimates based on unsmoothed returns becomes a function of the choice of unsmoothing methodology, rather than the data itself. Starting from an extremely smooth data series, it is ultimately the method that will provide the data.

To demonstrate this last point, we implement two unsmoothing methods based on Geltner's autoregressive filtering: the first one removes the autocorrelation using one lag and the second one uses two (see appendix 7.1 for details). The results are shown in table 11: the two unsmoothing methods produce very different optimal allocations to infrastructure with a difference of almost 13%, because of a single extra lag in the unsmoothing of the Preqin returns...

Crucially, because unsmoothing is not based on economic fundamentals, it does not change the results we obtained above: the substitution behaviour with stocks and bonds remains inconsistent. The Preqin proxy still replaces both equities and bonds in the 60/40 portfolio and continues to dominate the other asset classes with unrealistically high allocation levels.

This completes our exhaustive review of appraisal-based indices. While these indices actually consist of unlisted infrastructure companies, their valuation practices and coverage make them an inappropriate candidate to represent unlisted infrastructure asset class. Even with unsmoothing methods, these indices remain unsuitable to be used as a relevant proxy to conduct a strategic asset allocation exercise, as they lead to further uncertainty by basing the results on the choice of the unsmoothing method. Given the extreme sensitivity of allocation exercises to risk/return parameter estimation, and therefore to the data, this model dependence of unsmoothed appraisal indices is just as unwelcome as the past dependence on the smoothed versions of the same indices.

Ultimately, one of the pragmatic conclusions that should be drawn from the limitations of this type of index is that it is better to give up on trying to carry out an allocation exercise rather than deducing it from such unreliable data.

We conclude that the EDHEC*infra* indices such as the infra300 are the only sensible choice of proxy of the unlisted infrastructure asset class, and we will focus only on this proxy for the rest of this paper.

Given that the infrastructure class includes highly diverse investment realities, whether it involves the nature of the assets, the business model or the price setting methods of the services rendered by this infrastructure, we have the intuition that there will be interest in taking this diversity into account in the allocation exercise. As such, we conduct a final test of the role of granularity in unlisted infrastructure benchmarks: using a range of EDHEC*infra* sub-indices, we examine the impact of investing in different segments of the unlisted infrastructure universe on asset allocation results.

4.4 Granularity matters

While the infra300 index is designed to represent the investable market in infrastructure asset class, the majority of investors are exposures to a

Table 11: Substitution of infrastructure in 60/40 portfolio with smooth vs unsmooth Preqin indices

Portfolio	Optimal weights			Portfolio return	Portfolio volatility
	Infra	Equity	Bonds		
60/40 substitution with Preqin index	68.9%	18.6%	12.5%	7.8%	5.8%
60/40 substitution with 1-lag unsmoothing*	46.3%	35.2%	18.6%	7.8%	8.5%
60/40 substitution with 2-lags unsmoothing*	59.2%	26.9%	13.9%	7.8%	7.2%

Sources: Preqin, Datastream: Equity (Russell 3000), Bonds (Bloomberg Barclays Aggregate) . Period: 2008 Q2 – 2019 Q4. Preqin index returns are net of fees.
*Unsmoothing is based on Geltner's approach with autocorrelation of 1 lag and 2 lags.

combination of segments of the infrastructure asset class. The global infrastructure asset class as a whole is easily not investable and each unlisted infrastructure portfolio includes a combination of geographic, sector and other biases, resulting from the different levels of access to the market and to individual deals of each investor.

While the market value of unlisted infrastructure investments is driven by a set of common risk factors, as we argued above, investing in each segment of this market creates different exposures to these risks. Thus, infrastructure projects tend to be smaller than infrastructure corporates, and social infrastructure projects tend to be more leveraged than road projects, etc.

As shown in appendix 7.2, EDHEC*infra* sub-indices are quite different in terms of their risk-return profiles, originating from the differences in business models and exposures to common risk factors such as leverage or profitability. We find a spread of up to 900bp in the historical return and 400-700bp in the historical volatility of these segments.

Hence, using the infra300 index as the proxy for one's unlisted infrastructure portfolio may be somewhat inaccurate and lead to suboptimal allocation choices. It may be more precise for investors to use a customised benchmark for their strategic allocation that captures the specific TICCS® segments of their infrastructure portfolio or strategy.

To illustrate this point, we use the same asset allocation exercise as in the previous section and switch between a global (infra300) or a more granular EDHEC*infra* indices. In table 12, we show the following results:

1) On the left-hand side (grey columns), we use the portfolio weights obtained when the infra300 index is the benchmark (29.5%), but report portfolio returns and risk when actually investing a subset of the universe such as the Power sector, Renewables, or a 50/50 mix between Utilities and Airports.
2) On the right-hand side (blue columns), we use the index of each segment as the proxy in the optimisation exercise instead of the infra300 index to determine the weight of the unlisted infrastructure allocation and report the (more optimal) portfolio weights, risk and returns
3) In the last right-hand side column, we show the difference in portfolio Sharpe ratio between using the infra300 to set the infrastructure allocation but actually investing in a subsegment of the universe and using the right proxy to do so.

We find that, with granular indices, the optimal allocation varies significantly compared with the one implied by using the infra300 index. Investors would allocate sub-optimally to infrastructure using a less appropriate benchmark which does not reflect the TICCS segments of their portfolios. In fact, in five out of the eight cases considered, investors would have fallen short of their preferred return target. But by using the most appropriate benchmark, the target return is achieved in all cases and there is up to a 6% improvement in the portfolio's Sharpe Ratio. A custom index like the 50/50 Utilities and Airports index leads to an optimal infrastructure allocation which is almost 10 percentage points lower and a portfolio Sharpe ratio 4% higher.

Table 12: Comparison between optimal portfolio allocation with infra300 and with granular sub-indices

Infra proxy	With infra300 weight (29.5%)			With optimal weights using the granular proxy						
	Portfolio return	Portfolio volatility	Portfolio Sharpe Ratio	Infra weight	Equity weight	Bonds weight	Portfolio return	Portfolio volatility	Portfolio Sharpe Ratio	Δ Sh. ratio
infra300	7.8%	8.2%	0.95	30%	28%	42%	7.8%	8.2%	0.95	-
Utilities	7.0%	9.0%	0.78	20%	45%	35%	7.8%	9.7%	0.81	3.8%
Power	7.9%	7.4%	1.08	41%	14%	45%	7.8%	6.9%	1.14	5.6%
Renew.	7.7%	8.1%	0.95	29%	30%	41%	7.8%	8.2%	0.95	0.0%
Social	6.9%	9.1%	0.76	18%	46%	35%	7.8%	9.7%	0.80	5.3%
Roads	6.5%	8.0%	0.81	28%	44%	28%	7.8%	9.5%	0.82	1.2%
Airports	7.9%	9.6%	0.82	19%	39%	42%	7.8%	9.1%	0.85	3.7%
Custom*	7.4%	9.2%	0.80	20%	41%	39%	7.8%	9.3%	0.84	4.3%

Sources: EDHEC*infra*, Datastream: Equity (Russell 3000), Bonds (Bloomberg Barclays Aggregate) . Period: 2008 Q2 – 2019 Q4. Returns are gross of fees in USD. All EDHEC*infra* sub-indices are value-weighted. * Custom benchmark: 50% Utilities / 50% Airports

In line with recent research on benchmark selection, these results show that the more precise the benchmark, the more robust the strategic asset allocation is to unlisted infrastructure equity.

This concludes the first part of this paper. We have established that listed and appraisal-based benchmarks are not reliable proxies of unlisted infrastructure and cannot be used for an allocation exercise for diametrically opposed reasons: listed infrastructure benchmarks have excessively high correlation with equities and appraisal-based infrastructure benchmarks, on the other hand, have *artificially* low correlation with both equities and bonds.

Even with a very simple optimisation exercise, we find that EDHEC*infra* indices are a much better proxy as they show a consistent substitution behaviour when added to a 60/40 portfolio, lead to a more reasonable allocation to infrastructure.

Moreover, the fact that the global indices offered by EDHEC*infra* can be analysed through sub-indices that are representative of segments that are consistent and important for infrastructure investment allows the reality of the investors' investments to be genuinely taken into account in terms of both risk and return profiles and allows the portfolio's risk-adjusted return to be improved for the same allocation to infrastructure, and also offers the opportunity to access granular data that reflects the different exposures to infrastructure risks found in individual portfolios.

In what follows, we use EDHEC*infra* data as the proxy for unlisted infrastructure and explore the role of infrastructure in a multi-asset class portfolio, taking a more robust forward-looking view and using several optimisation methodologies.

5. Infrastructure in a multi-asset class framework

In this section, we address a more normative but also essential question: what is the role of unlisted infrastructure in the multi-asset portfolio allocation?

We look at 10 asset classes. In practice, most investor portfolios contain multiple asset classes in a portfolio including traditional and alternative investments. We start with four traditional asset classes: US equity, emerging markets equity, corporate bonds, and government bonds. We also include six alternative asset classes: private equity, real estate, hedge funds, commodities, unlisted infrastructure equity and infrastructure debt.

We introduce the distinction between unlisted infrastructure equity and infrastructure debt since there are important differences in their investment characteristics and EDHEC*infra* also produces private infrastructure debt indices, for which there exists, to our knowledge, no appraisal-based or listed proxy[1].

Private infrastructure debt is exposed to duration and credit risks as well as a combination of risks specific to its TICCS segments. These unique characteristics imply that infrastructure debt can play a different role in an asset-liability framework than unlisted infrastructure equity which may be more attractive for its return-seeking properties.

In what follows, we first describe the forward-looking data used in this exercise, then define two typical investor profiles to compare different allocation results. Finally, we report strategic asset allocation results using a range of portfolio optimisation methods.

5.1 Forward-looking data

In the first part of this paper, we have used in-sample data in combination with a return targeting optimisation exercise, which by definition focuses on return estimates. The results obtained were thus highly dependent on the sample itself. And as we have mentioned previously, the available historical sample, which includes a period of significant valuation appreciation for unlisted infrastructure equity, may not be a fair representation of forward-looking risks and returns.

Forward-looking estimates of return, volatility and correlations are a better way to address the question: what should the role of unlisted infrastructure be in a multi-asset portfolio today?

For asset classes other than infrastructure, we rely on the industry estimates, representing a wide-spectrum of financial institutions, which are formed as a combination of long-term historical observations and forward-looking views based on short-term variations in risk and return of each asset class. We consider the forward-looking data provided by the leading consultants and asset managers, Blackrock, JP Morgan, Morgan Stanley, BNY Mellon, Invesco, Schroders, Northern Trust, State Street, Callan and Envestnet, reported at the end of 2019/ beginning of 2020, and use the average of these views as our forward-looking estimate. The data provided by each organisation is available in appendix 7.4 and their average estimates are presented in tables 13 and 14.

1 - More details on the data and methodology used to compute EDHEC*infra* debt indices can be found on the EDHEC*infra* website: docs.EDHEC*infra*.com

These estimates are supposed to be a guiding point. In practice, investors may have their own preferred benchmarks to develop these forward-looking views.

For infrastructure, we use the expected returns estimated by EDHEC*infra*. As described above, EDHEC*infra* indices are driven by a valuation methodology which consists of estimating market expected returns (equity risk premia and debt credit spreads) at each point in time, using the latest primary and secondary market transaction prices.

Each quarter, the market discount rates of hundreds of equity investments and debt instruments are estimated by updating a multi-factor model of expected returns, given 1/ what the estimates were until then 2/ how new market price data suggests they have evolved since the last estimation.

Since, in equilibrium, discount rates are equivalent to expected returns, the EDHEC*infra* methodology boils down, in effect, to estimating expected returns each quarter. Moreover, because they represent the average price of a combination systematically rewarded risks as shown above, these expected returns can be considered net of any alpha and therefore also net of any fees.

Figure 2 shows expected returns for unlisted infrastructure equity and private infrastructure debt indices over the 2015-2020 period. We use the infra300 for unlisted infra equity and the EDHEC*infra* broad market index to represent private infrastructure debt market.

As noted above, the infrastructure asset class went through a transition from lower to significantly higher valuations in the years immediately following the 2008 financial crisis. These expected returns have remained on average stable since 2015 at around 7-8% for unlisted infrastructure equity and around 2-3% for infrastructure debt.

In what follows, we use an average of the expected returns over the past five years as the estimate of forward-looking return, as shown in table 13. Likewise, expected risk estimates of unlisted infrastructure equity and private infrastructure debt are based on the historical volatility of quarterly total returns over the same five-year period as above, which represents a reasonable estimate for forward-looking risk.

For correlations, we take a longer time period and we use the correlations between infrastructure and other asset classes from 2003 to 2019 as the best estimate. Furthermore, due to the lack of any appropriate long-term benchmarks for private equity, we assume the correlations between infrastructure and private equity are the same as with US equities. These correlations are presented in table 14.

Next, we define two standard investor profiles.

5.2 Investor profiles

Portfolio allocations are a direct function of the investment objectives of investors including their risk and return targets, time horizon, investment focus, etc. In what follows we compute optimal portfolio weights for a range of risk, return and diversification targets. Hence to improve the interpretation of the results we begin by defining two typical investor profiles, shown in table 15.

The first type is a conservative investor equivalent to a "20/80" portfolio style i.e., a 20% allocation to US equities and 80% allocation to corporate bonds. This profile is akin to a well-funded pension plan and with a focus on liability-driven investment. Their asset allocation goal would typically be to protect the existing fund contributions and hedge liabilities at the lowest possible cost. Traditionally, they use bonds due to their natural ability to hedge the liabilities through interest rate exposure, However, alternative investments like infrastructure debt could allow such investors to achieve more cost-

Table 13: Average industry consensus for expectations of risk and return YE2019

Asset class	Return	Risk	Sharpe ratio
Infrastructure equity	7.2%	12.8%	0.56
Private Infrastructure debt	2.9%	3.6%	0.81
US equity	5.9%	15.5%	0.38
Emerging equity	8.0%	21.2%	0.38
Corp bonds	2.0%	6.0%	0.32
Gov bonds	1.2%	5.0%	0.23
Real estate	6.7%	10.8%	0.61
Private equity	8.7%	21.1%	0.41
Hedge funds	4.1%	6.9%	0.60
Commodity	3.2%	16.5%	0.19

Sources: EDHEC*infra* (infra equity is infra300 USD and infra debt is the broad market private debt index USD), Other asset classes expectations are based on the estimates of investment managers and consultants: *Blackrock, JP Morgan, Morgan Stanley, BNY Mellon, Invesco, Schroders, Northern Trust, State Street, Callan and Envestnet*. Infra returns are calculated as the average expected returns from 2015 – 2019. Infra volatility is based on in-sample total return volatility from 2015-2019. *Sharpe ratio assumed a risk-free rate of zero. All returns in USD.

Table 14: Industry expectations of asset class correlations

	Infra equity	Infra debt	US equity	Emerg equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
Infra equity	1	0.25	0.2	0.2	0.25	0.35	0.45	0.2	0.15	0.1
Infra debt	0.25	1	-0.35	-0.3	-0.1	0.4	-0.1	-0.35	-0.4	-0.3
US equity	0.2	-0.35	1	0.71	0.27	-0.16	0.43	0.78	0.72	0.3
Emerg equity	0.2	-0.3	0.71	1	0.32	-0.15	0.36	0.65	0.67	0.39
Corp bonds	0.25	-0.1	0.27	0.32	1	0.65	0.08	0.17	0.44	0.13
Gov bonds	0.35	0.4	-0.16	-0.15	0.65	1	-0.23	-0.41	0.02	-0.14
Real estate	0.45	-0.1	0.43	0.36	0.08	-0.23	1	0.45	0.35	0.19
Private equity	0.2	-0.35	0.78	0.65	0.17	-0.41	0.45	1	0.65	0.31
Hedge funds	0.15	-0.4	0.72	0.67	0.44	0.02	0.35	0.65	1	0.35
Comm-odity	0.1	-0.3	0.3	0.39	0.13	-0.14	0.19	0.31	0.35	1

Sources: EDHEC*infra* (infra equity is infra300® USD and infra debt is the broad market private debt index USD), Other asset classes expectations are based on the estimates of investment managers and consultants: *Blackrock, JP Morgan, Morgan Stanley, BNY Mellon, Invesco, Schroders, Northern Trust, State Street, Callan and Envestnet*. Infra correlations are based on long-term in-sample data from 2003-2019. Correlations between infra and private equity are assumed to be the same as with equity. All estimations using USD returns. For unlisted infrastructure equity and private infrastructure debt, we use EDHEC*infra*'s estimates which are updated each quarter using an explicit Bayesian approach, thus, reducing sample-dependency.

effective liability hedging thanks to superior returns in private debt. As shown in table 16, this portfolio has an expected return of 2.8% and an expected risk of 6.8%, using the inputs from table 14.

The second profile is that of a more aggressive investor with a "60/40" style i.e., a 60% allocation to US equities and 40% allocation to corporate bonds. This profile is commonly associated with an under-funded pension plan focused in seeking growth in order to limit the increase of member contributions. Such an investor would have a higher risk tolerance and want to achieve higher returns. The annualised expected return and risk of this portfolios stands at 4.3% and 10.8%, also using the table 14 inputs.

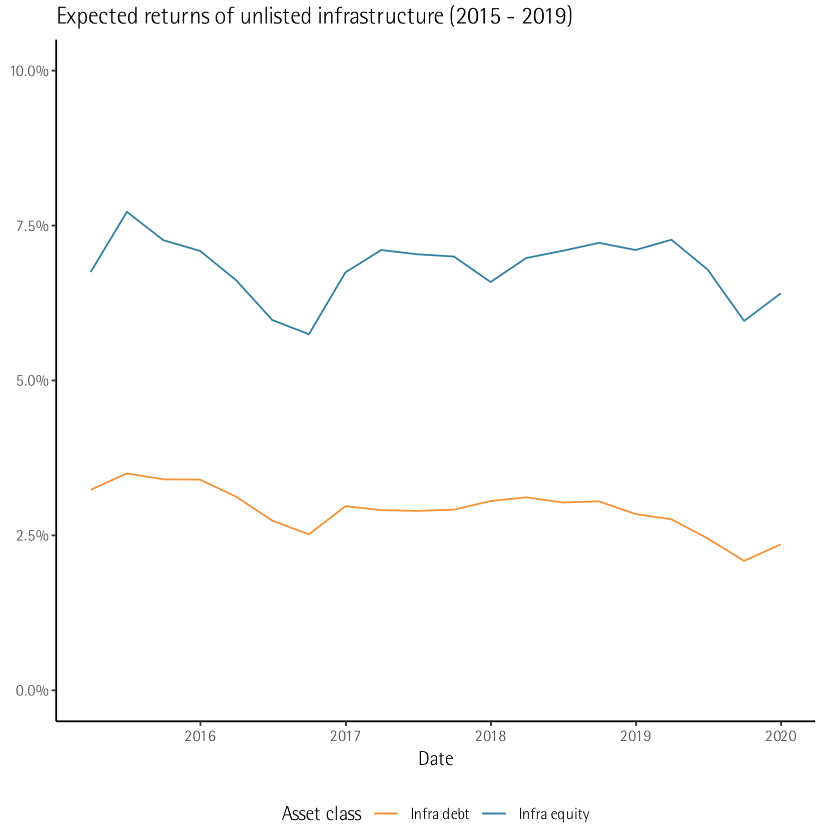
Next, we implement several portfolio optimisation methods and report the resulting allocations to unlisted infrastructure equity and debt for each investor profiles.

5.3 Portfolio optimisation

An optimal portfolio is an 'efficient' combination of the assets available on the risk-return spectrum. It should satisfy the requirement that no other set of weights exists with a higher expected return given a certain level of risk.

This approach which is at the heart of modern finance requires a robust estimate of expected returns. Unfortunately, such robust return estimators can be difficult to obtain, as Robert

Figure 2: Expected returns of unlisted infrastructure equity and private infrastructure debt for the past five years



Source: EDHEC*infra*. Infra equity: infra300; Infra debt: broad-market debt value-weighted

Table 15: Typical investor profiles used to compare optimal allocations

	Conservative: '20/80' investor	Aggressive: '60/40' investor
Funding status	Over-funded	Under-funded
Objective	Hedge liabilities	Invest in growth portfolio
Proxy	20/80 portfolio (20% allocation to equity and 80% to bonds)	60/40 portfolio (60% allocation to equity and 40% to bonds)
Target return	2.8%	4.3%
Target risk	6.8%	10.6%

Sources: Risk and return estimates are based on the average industry expectations of US equity and corporate bonds.

Merton famously put it "even if the expected return on the market were known to be a constant for all time, it would take a very long history of returns to obtain an accurate estimate." (Merton, 1980, p.5). In the same paper, Merton continues: "the unanticipated part of the market return should not be forecastable by any predetermined variables. Hence, unless a significant portion of the variance of the market returns is caused by changes in the expected return on the market, it will be difficult to use the time series of realised market returns to distinguish among different models for expected return."

In other words, unlike with estimates of risk, we cannot necessarily rely on return data converging towards a true long-term estimate as more return data is being observed.

Hence, we compute a range of possible allocations given an explicit range of return or risk targets. Moreover, investors may have a range of different objectives, and the classic return maximisation optimisation problem is not always the best suited to a strategic asset allocation. In what follows we implement two types of mean-variance optimisations -- return-targeting and risk-targeting -- and a risk-only optimisation technique, which avoids using returns altogether and is instead based on the risk contributions of each asset class to the portfolio.

5.3.1 Return targeting

The objective of this portfolio optimisation approach is to find the allocation that achieves a portfolio return equal to or greater than a fixed target while minimising portfolio risk, with no shorts and no cash (fully invested portfolio). We add two more constraints:

- the effective number of asset classes (ENC)[2] must be at least equal to six (out of 10).
- the cumulative allocation to all illiquid asset classes (infrastructure, real estate, private equity and hedge funds) cannot exceed 20% of the portfolio.

The optimisation problem is detailed in appendix 7.3.1.

We compute optimal weights for a range[3] of portfolio return targets from 2% to 5.5%. The results are shown in figure 3 and table 16 which details the optimal weights and portfolio characteristics of the two investor profiles previously described.

First, we compare the portfolio with or without any infrastructure. As shown at the bottom of table 16, using the same optimisation setup and constraints, we find that adding infrastructure to a multi-asset class portfolio can improve the Sharpe ratio by up to 6%.

Next, we find that the total allocation to infrastructure (debt and equity) is quite stable, between 10% and 13%, irrespective of the return target used (figure 3).

The two investor profiles shown in table 16 both have a total infrastructure allocation of more than 10% but the composition of this infrastructure allocation varies depending on the investor profile.

Both achieve quite comparable portfolio Sharpe ratios: for the more conservative (20/80) investor style, infrastructure debt dominates and substitutes the need to have more bonds in the portfolio. In fact, with a better risk-adjusted return than corporate or government bonds, it can help reduce the cost of hedging liabilities significantly while providing the desired duration. This profile also invests less in listed equities and real estate.

The 60/40 investors, which are more focused on return-seeking investments, invest more in listed equities including emerging markets and also receive an infrastructure allocation of about 10% but it is exclusively dedicated to unlisted infrastructure equity.

The absence of private equity from most optimal portfolios results, except for the ones with a very high return target, is the result of the consensus risk and return estimates used and described above. As shown in table 13 previously, private equity has an average expected volatility of more than 21%, the highest among all alternative asset classes considered, and has a correlation with equities above 75%, thus reducing its diversification potential. In a way, infrastructure, with a better risk-adjusted return and lower correlations with other asset classes, substitutes the role of private equity in the portfolio.

As a confirmation of this point, in the exercise excluding infrastructure from the mix of asset classes, we find private equity does play a role in the portfolio with an allocation of up to 8.6% for the high return targets.

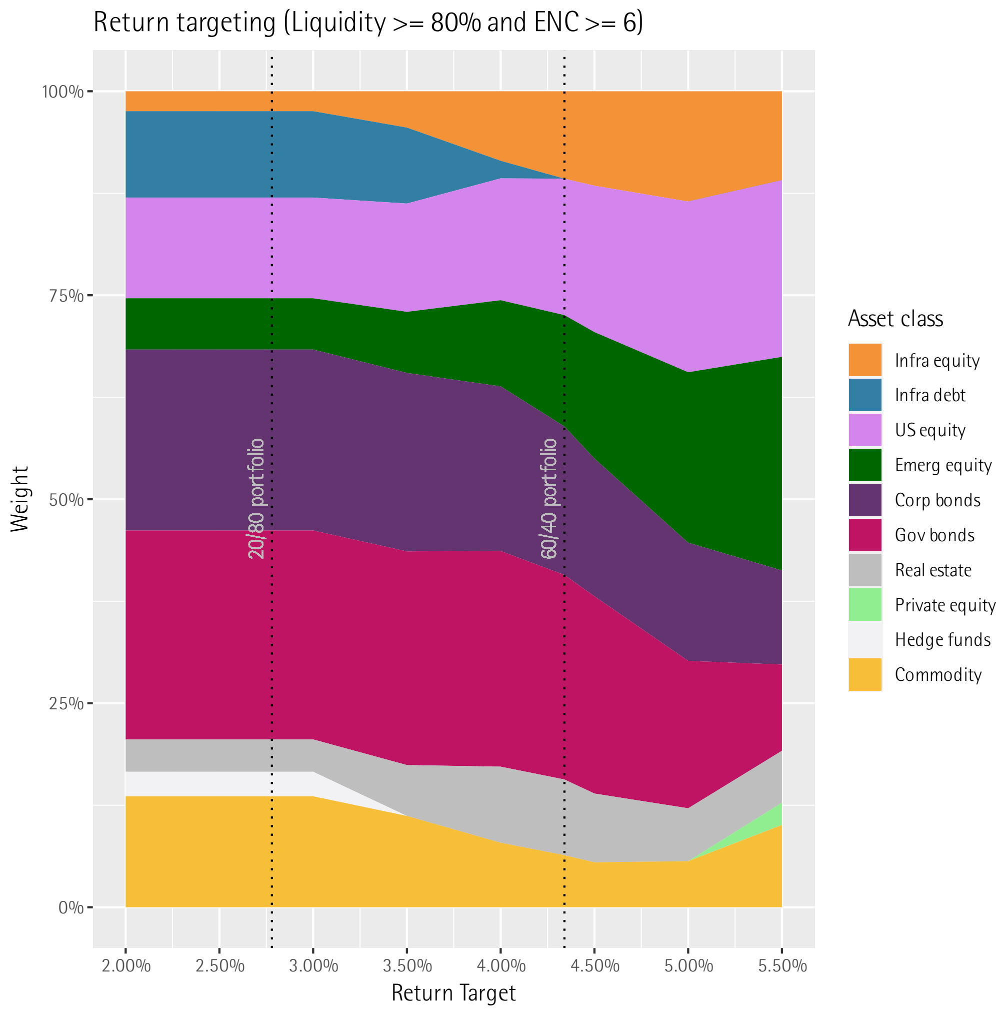
5.3.2 Risk targeting

This approach requires defining an explicit portfolio risk target before finding the optimal portfolio weights: the objective is to find the allocation which keeps the portfolio risk level

2 - Effective number of asset classes or ENC is a measure of diversification and is given by the reciprocal of the sum of the squared weights of each asset class in the portfolio.

3 - The range of 2% to 5.5% covers all possible portfolios under the given constraints.

Figure 3: Optimal allocation with return-targeting approach under different target return constraints



Source: EDHEC*infra*.

Table 16: Multi-asset portfolio including infrastructure equity and debt while targeting a return level

	Asset class	'20/80' investor	'60/40' investor
Return target		2.78%	4.34%
Weights	Infra equity	2.4%	10.7%
	Infra debt	10.6%	0.0%
	US equity	12.3%	16.7%
	Emerging equity	6.3%	13.6%
	Corporate bonds	22.2%	18.2%
	Gov bonds	25.6%	25.1%
	Real estate	4.0%	9.3%
	Private equity	0.0%	0.0%
	Hedge funds	3.0%	0.0%
	Commodity	13.6%	6.4%
Portfolio return		3.29%	4.34%
Portfolio risk		5.41%	7.10%
Sharpe ratio		0.608	0.611
Sharpe ratio without infra*		0.573	0.581

Source: EDHEC*infra*. *Same optimisation problem but excluding infra equity and infra debt from the portfolio.

below the target while maximising portfolio returns.

We use the same constraints as above: a diversification constraint of at least six effective asset classes and a illiquidity constraint of less than 20%. The optimisation problem is detailed in appendix 7.3.2.

We implement this exercise using a range of volatility targets, ranging from 5.5% to 12%, which span all possible portfolio volatilities under the pre-defined constraints. The volatility targets of the two investor profiles are the ones indicated above in table 16. The results are presented in figure 4 and the details for the two investor profiles in table 17.

Unsurprisingly, with a higher risk tolerance, the allocation shifts from fixed income assets to riskier assets. As with the previous approach, we find that the total allocation to infrastructure remains stable and significant in all portfolios irrespective the chosen risk-target. With both the 20/80 and 60/40 investor profiles, we again find an infrastructure allocation of around 10% largely consistent with the results of return-targeting approach.

Infrastructure debt however disappears from the portfolio for risk-targets greater than 6.5% including for our two investor profiles: the objective of maximising returns while keeping portfolio risk below a target privileges infrastructure equity, which has a higher return than infrastructure debt, given the 20% illiquidity constraint, forces the substitution of infrastructure debt for infrastructure equity. In tests using a relaxed illiquidity constraint, we find a greater participation from both infrastructure equity and debt, with the latter replacing a large allocation away from bonds.

The 60/40 investor profile achieves a much lower Portfolio Sharpe ratio than the 20/80 profile in this setting.

As we can therefore observe, and beyond the quantities, which always depend on the risk or return assumptions, by using the same set of return, correlation and risk data, the objectives of the allocation can have a strong influence on the composition of the optimal portfolios that meet the objectives. These observations show that when we can use true policy benchmarks to represent the infrastructure class, it is genuinely possible to avoid being limited to a segregated sleeve whose value is defined without any link to the investor's expectations in terms of the risk/return combination of their portfolio, and to be able to integrate this asset class into the allocation menu.

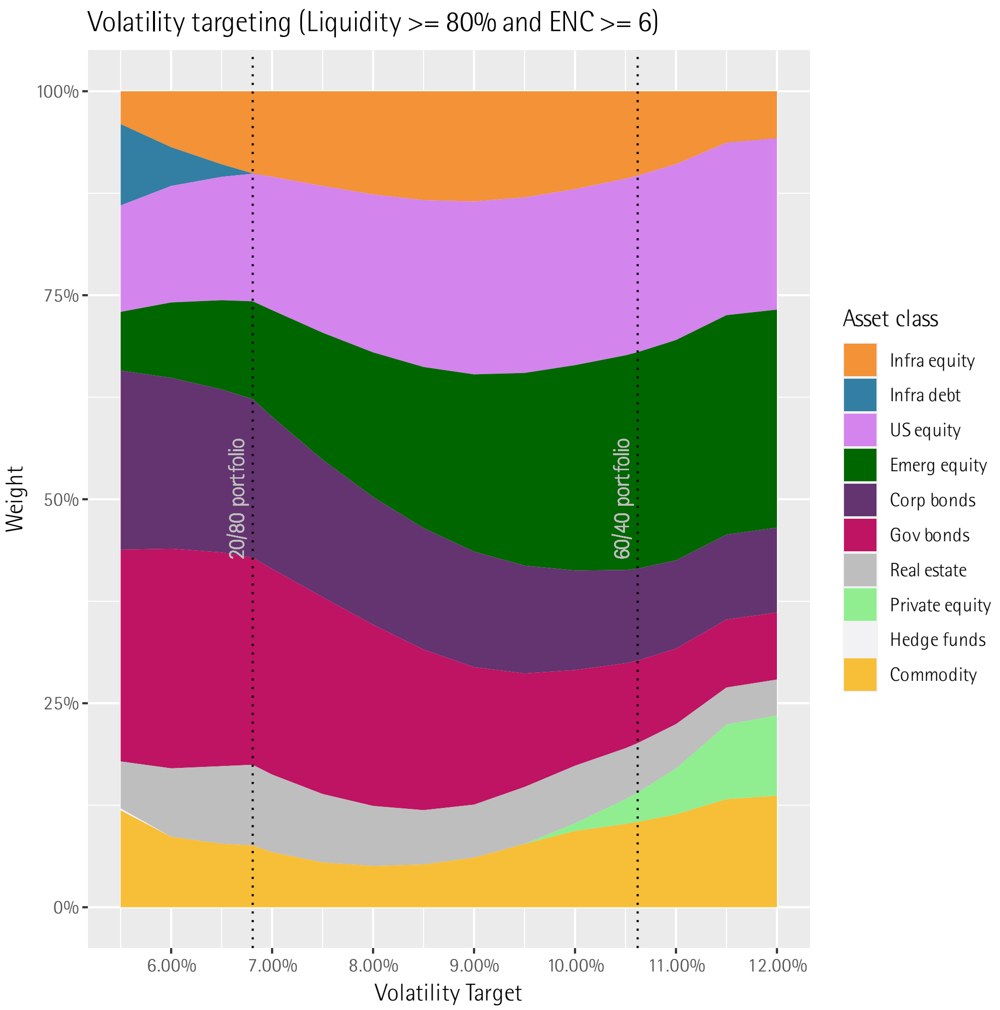
5.3.3 Equal risk contribution

In this section, and as we have already underlined, in order to avoid the allocation depending on return estimations that are always sample-dependent, we implement a risk contribution approach that uses only the volatilities and correlations of each asset class to determine their contribution to the risk of the portfolio: the objective is to find the portfolio weights that minimise the risk contribution from all asset classes while achieving a minimum effective number of asset classes defined as an explicit target in the problem.4

We also test the sensitivity of the final allocations to the ENC target by letting it vary from three to seven (out of 10 asset classes), and keep a liquidity constraint set to a maximum of 20% illiquid assets. This approach deviates from the standard 'equal risk contribution' approach due to the added constraints. In an unconstrainted setting, the same optimisation objective would lead to an equal risk contribution from all asset classes. The optimisation problem is detailed in appendix 7.3.3.

4 - Both risk contribution objectives and ENC target constraints can be used for diversification purposes, with the former directly diversifying the risk and the latter doing it indirectly through weights.

Figure 4: Optimal allocation with risk-targeting approach under different risk targets



Source: EDHEC*infra*.

Table 17: Multi-asset portfolio including infrastructure equity and debt while targeting a risk level

	Asset class	'20/80' investor	'60/40' investor
Risk target		6.81%	10.62%
Weights	Infra equity	10.1%	10.3%
	Infra debt	0.0%	0.0%
	US equity	15.6%	21.6%
	Emerging equity	12.0%	26.5%
	Corporate bonds	19.4%	11.3%
	Gov bonds	25.4%	10.1%
	Real estate	9.9%	6.1%
	Private equity	0.0%	3.6%
	Hedge funds	0.0%	0.0%
	Commodity	13.6%	10.5%
Portfolio return		4.21%	5.54%
Portfolio risk		6.81%	10.62%
Sharpe ratio		0.62	0.52

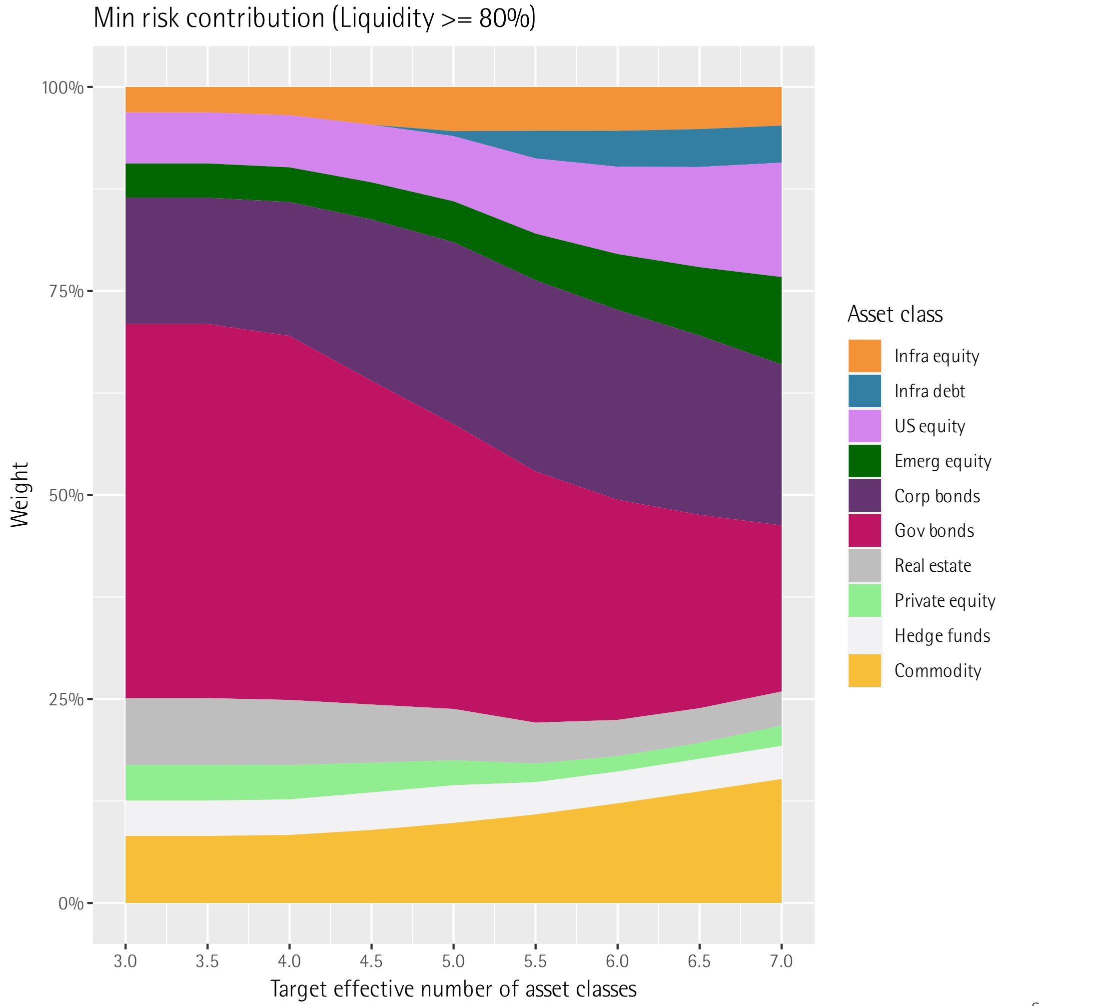
Source: EDHEC*infra*. *Same optimisation problem but excluding infra equity and infra debt from the portfolio.

Table 18: Multi-asset portfolio including infrastructure equity and debt while minimising risk contributions

	Asset class	High ENC target	Mid ENC target	Low ENC target
ENC target		7	6	5
Weights	Infra equity	4.7%	5.3%	5.4%
	Infra debt	4.5%	4.5%	0.6%
	US equity	14.0%	10.7%	8.0%
	Emerging equity	10.7%	6.8%	5.0%
	Corporate bonds	19.7%	23.3%	22.3%
	Gov bonds	20.4%	27.0%	34.9%
	Real estate	4.2%	4.4%	6.3%
	Private equity	2.5%	1.9%	3.1%
	Hedge funds	4.1%	3.9%	4.6%
	Commodity	15.2%	12.2%	9.8%
Portfolio return		3.94%	3.53%	3.34%
Portfolio risk		6.95%	5.75%	5.31%
Sharpe ratio		0.57	0.61	0.63

Source: EDHEC*infra*. *Same optimisation problem but excluding infra equity and infra debt from the portfolio.

Figure 5: Optimal allocation using equal risk contribution approach under different ENC targets



Source: EDHEC*infra*.

In this setting, we do not resort to investor profiles since no expected return level is set. Figure 5 shows the results for varying ENC targets and table 18 the detailed results for three specific cases: low (5), medium (6) and high (7) ENC target.

With a low ENC target of three, fixed income has the highest allocation in the portfolio, in line with the focus of this approach to minimise the risk contributions. As the ENC target increases, the weights of other asset classes must increase in order to satisfy the ENC constraint, making the individual risk contribution less equal. Thus, the volatility of the portfolio increases from 5.31% for the low ENC target to 6.95% for the highest ENC target, as shown in table 18.

Consistent with the previous results, for ENC targets of five or above, the allocation to infrastructure is in the same range of about 10% in total evenly split between infrastructure equity and debt.

Thus, we have compared optimal allocation results using three different optimisation techniques focusing on targeting returns, risk levels and risk contributions: we find a consistent allocation to unlisted infrastructure with varying allocations between equity and debt depending on the type of investor profile. Clearly, infrastructure always has a role to play in a multi-asset portfolio as a strategic asset class in the sense that it completes the other allocation classes and due to the proper appreciation of this completeness by policy benchmarks that are appropriate, notably in terms of correlation with the other classes, which allows the infrastructure allocation to be seen as the investor's core investment rather than a satellite sleeve.

6. Conclusions

In this paper, we argued that while asset allocation is a first-order question for investors, too often allocation to an alternative asset class like infrastructure is made on an *ad hoc* and fairly conservative basis due to a long-time lack of robust and realistic data.

To make this point we showed that it is not possible for investors to use listed or appraisal-based indices as proxies for unlisted infrastructure to conduct a meaningful asset allocation exercise.

In line with previous research, we found that listed infrastructure indices are too correlated with equities to make any meaningful difference in a multi-asset class investment strategy. Listed infrastructure is fully exposed to equity risk and can at best be classified as a segment of equity asset class rather than a suitable proxy for unlisted infrastructure.

We also looked at an appraisal-based unlisted infrastructure index in depth and determined that is not fit for asset allocation purposes. We showed that the returns of such index are smooth, leading to unrealistic levels of volatility and correlations with other asset classes. We also showed that unsmoothing them did not resolve these issues but instead made the asset allocation results a function of the choice of unsmoothing technique. We also confirmed that appraisal-based data is not adequate further by implementing a simple in-sample substitution test in a traditional 60/40 portfolio and found that this type of data leads to unreasonable results and has an inconsistent substitution behaviour with equities and bonds.

We argued in favour of using EDHEC*infra* indices as the only suitable proxy available for infrastructure as these indices are marked-to-market, leading to a returns series which has statistically insignificant serial correlations and exhibit believable measures of risk and correlations with other asset classes. We showed that EDHEC*infra* indices give consistent results by substituting primarily equities and also resulting in a much more reasonable allocation to infrastructure.

To appreciate the usefulness of taking the risk and return characteristics of unlisted infrastructure into account as an asset class in a realistic and rigorous way, we then developed a forward-looking Strategic Asset Allocation exercise in a multi-asset class framework to determine what role unlisted infrastructure equity and debt could play in the total portfolio using EDHEC*infra* data for unlisted equity and private infra debt, and industry consensus for eight other asset classes.

We show that infrastructure always has a role to play in institutional portfolios: we find consistent allocations to infrastructure, typically around 10%, using different optimisation techniques and parameters, and considering different investor profiles.

One of the main results in a return targeting framework is the dichotomy between the role of unlisted infrastructure and private infrastructure debt.

Return-seeking investors can allocate more, if not exclusively, to unlisted infrastructure equity, which exhibits an attractive Sharpe ratio and limited correlations with other asset classes.

For more conservative investors, likely to be better funded, the role of private infrastructure debt can be significant either in addition or in substitution of unlisted infrastructure equity. Infrastructure debt can substitute other fixed income assets and improve the cost of liability hedging thanks to its higher yield.

This capacity to take different objectives into account and to participate with other asset classes through substitution between these different components shows the usefulness of Strategic Asset Allocation that takes the infrastructure investment into account and does not limit it to an exercise whereby infrastructure is considered to be a segregated investment sleeve on the pretext of its illiquidity and absolute return nature.

Another attractive characteristic of both infrastructure equity and infrastructure debt is that they correspond to large long-term cash flows and, like for all financial instruments, discounting these cash flows provides the present value of these investments.

This discount rate contains both an interest rate component, which corresponds to the preference for the present, and a risk premium, which corresponds to a risk of variability in the cash flows in the case of infra equity, and corresponds to default risk in the case of infra debt. Beyond the traditional SAA approach from an asset management perspective, as we have explored in the present document, these characteristics can be useful from an ALM perspective, where infrastructure will not only be used as a risky asset class in order to improve the diversification of the performance-seeking portfolio, and as such limit its risk and its possible impact on the volatility of the funding ratio, but will also be explicitly considered to be a component of the hedging portfolio.

Indeed, long-term investors have few options for asset-liability matching while simultaneously limiting volatility. Traditionally, long-maturity bonds are used for liability-hedging because of their high interest rate exposure. However, in today's environment of ever-low rates, "real" yields on the highest quality bonds have turned negative in most developed markets. This is where infrastructure can shine as it offers higher expected returns than bonds, and, more importantly, a positive cash yield to investors.

Given the relatively low levels of cash flow volatility and default risk, investors have logically envisaged using infrastructure investment in the context of liability-driven investing (LDI), thus, substituting the role of bonds in institutional portfolios. But, clearly, for infrastructure to be a suitable LDI asset class, pension funds need to be able to gain exposure in a risk-controlled and diversified way.

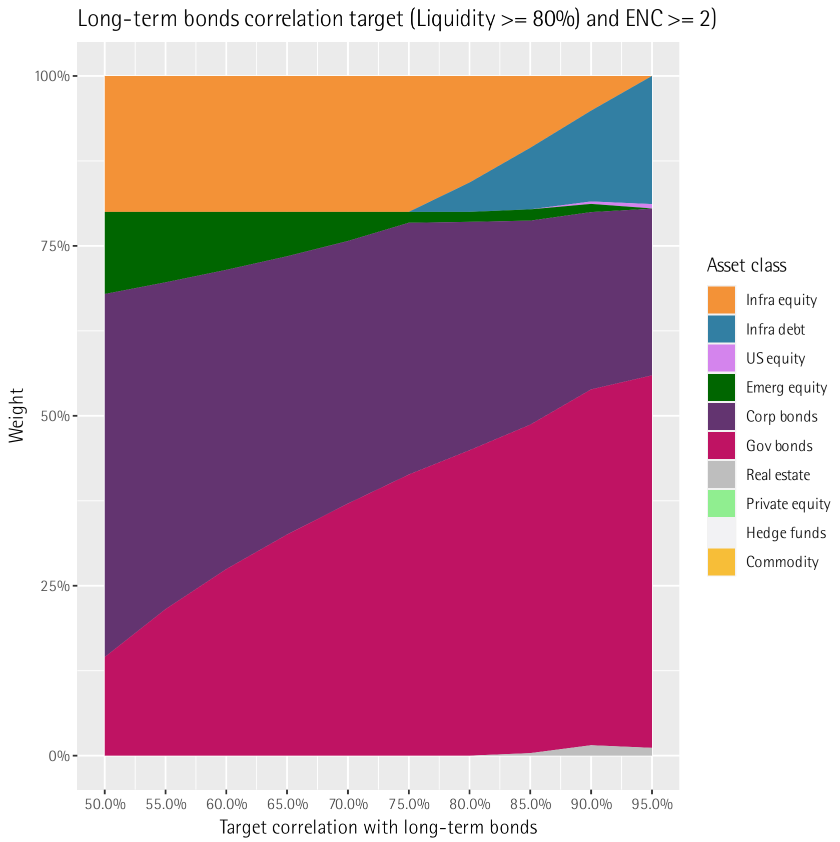
Hence, continuing the argument made in this paper, if the objective is to take account of liabilities that are valued as fair value or mark-to-market, it is important that the ingredients of the hedging portfolio for these liabilities be valued with the same methods. As a candidate for the constitution of the hedging portfolio, it is important for the infrastructure class to be able to be represented by a mark-to-market policy benchmark like the EDHEC*infra* indices.

As a rather basic illustration of this explicit integration of an ALM objective, with the same forward-looking data as outlined in this paper, we implement an asset allocation exercise[1] for an investor targeting a correlation level with long-term bonds (a proxy for liabilities) while maximising the return. The allocation results are displayed in figure 6.

We find that with a moderate correlation target of 60-70%, infra equity takes all the illiquid allocation to maximise the portfolio return. But with a better liability hedge and a higher correlation target, infrastructure debt would indeed substitute the role of bonds in traditional portfolios.

1 - Effective asset classes of greater than 2, since there are fewer candidates which have high correlation with bonds. Also add an illiquidity constraint of 20% to limit the exposure to alternative investments.

Figure 6: Optimal allocation targeting different correlation levels with long-term bonds



Source: EDHEC*infra*.

This exercise, which does not take account of the separation theorem between the return-seeking portfolio and the liability-hedging portfolio or the formalisation of the interactions between these portfolios, nonetheless gives a glimpse of an important role for the infrastructure class in institutional portfolios, not only from an AM perspective, but also from an ALM perspective.

As such, future EDHEC*infra* research will aim to characterise and quantify the benefits of infrastructure investment in an LDI context.

7. Appendix

7.1 Unsmoothing methodologies

7.1.1 First-order autoregressive filtering

Removes first-order serial correlation in the returns as follows:

$$R_t' = \frac{R_t - \alpha_1 \times R_{t-1}}{1 - \alpha_1}$$

Where,

R_t' is the un-smoothed return at time t
R_t is the observed return at time t
α_1 is the un-smoothing parameter (first-lagged correlation)

7.1.2 Second-order autoregressive filtering

Removes first and second order serial correlation in the returns as follows:

$$R_t' = \frac{R_t - \alpha_1 \times R_{t-1} - \alpha_2 \times R_{t-2}}{1 - \alpha_1 - \alpha_2}$$

Where,

R_t' is the un-smoothed return at time t
R_t is the observed return at time t
α_1, α_2 are the un-smoothing parameters (first and second-lagged correlations)

7.2 Granular indices spreads

Table 19 shows the top and bottom EDHEC*infra* sub-indices by return and volatility on a 5-year and 10-year basis. It also highlights the spread between the top and bottom numbers.

7.3 Optimisation problems

7.3.1 Return targeting

$$\min_{\omega} \left(\omega' \Omega \omega \right)$$

With the constraints:

1. Portfolio return is greater than the target level: $\omega' \mu \geq R_p$
2. No short positions allowed: $\omega_i \geq 0, \ \forall i$
3. All weights add up to 1: $\sum \omega = 1$
4. Max. 20% portfolio is allocated to illiquid assets : $\sum \omega_i \leq 0.2, \ \forall i \in [infra, real\,estate, private\,equity, hedge\,funds]$
5. Effective number of asset classes is at least 6: $\frac{1}{\sum \omega^2} \geq 6$

where,

ω is a vector of asset class weights

μ is a vector of the expected returns of the different asset classes

Ω is the covariance matrix of the different asset classes

R_p is the target portfolio return.

7.3.2 Risk targeting

$$\max_{\omega} \left(\omega' \mu \right)$$

With the constraints:

1. Portfolio volatility is less than the target level: $\sqrt{\omega' \Omega \omega} \leq \sigma_p$
2. No short positions allowed: $\omega_i \geq 0, \ \forall i$
3. All weights add up to 1: $\sum \omega = 1$
4. Max. 20% portfolio is allocated to illiquid assets : $\sum \omega_i \leq 0.2, \ \forall i \in [infra, real\,estate, private\,equity, hedge\,funds]$
5. Effective number of asset classes is at least 6: $\frac{1}{\sum \omega^2} \geq 6$

where,

Table 19: Top, bottom and spread of total return and volatility of EDHEC*infra* indices

	5-year annualised	10-year annualised
Top return	12.61% (Advanced Economies Power Generation)	18.29% (Advanced Economies Power Generation)
Bottom return	3.79% (Advanced Economies Social infrastructure)	9.55% (Australia Contracted Projects)
Return Spread	882bp	874bp

Highest Volatility	16.66% (Emerging Markets Infrastructure)	16.40% (Broadmarket Network Utilities)
Lowest Volatility	9.46% (Advanced Economies Contracted Infrastructure)	11.46% (Broadmarket Contracted Infrastructure)
Volatility Spread	720bp	494bp

Source: EDHEC*infra*, Q1 2020

ω is a vector of asset class weights

μ is a vector of the expected returns of the different asset classes

Ω is the covariance matrix of the different asset classes

σ_p is the target portfolio volatility

7.3.3 Equal risk contribution

$$\min_{\omega} \sum_i \sum_j \left(\omega_i \frac{\partial \sigma_p}{\partial \omega_i} - \omega_j \frac{\partial \sigma_p}{\partial \omega_j} \right)^2$$

With the constraints:

1. No short positions allowed: $\omega_i \geq 0, \ \forall i$
2. All weights add up to 1: $\sum \omega = 1$
3. Max. 20% portfolio is allocated to illiquid assets : $\sum \omega_i \leq 0.2, \ \forall i \in [infra, real\,estate, private\,equity, hedge\,funds]$
4. Effective number of asset classes is greater than the target: $\frac{1}{\sum \omega^2} \geq ENC$

where,

ω is a vector of asset class weights

σ_p is the portfolio volatility

ENC is the target number of effective asset classes in the portfolio

7.4 Industry estimates

7.4.1 Return expectations

Table 20 shows the estimates of expected returns of different asset classes by each provider considered in this paper.

7.4.2 Risk expectations

Table 21 shows the estimates of expected risk in different asset classes by each provider considered in this paper.

7.4.3 Correlation expectations

tables 22 to 27 show the estimates of correlations between different asset classes by different providers considered in this paper.

Table 20: Expected return estimates from leading asset managers and consultants

Asset class	Blackrock	JP Morgan	BNY Mellon	Northern Trust	Morgan Stanley	Invesco	Schroders	State Street	Callan	Envestnet PMC
US equity	5.8%	7.2%	6.2%	4.7%	4.8%	4.5%	5.9%	6.2%	7.2%	6.5%
Emerging equity	7.3%	10.5%	8.5%	5.4%	7.7%	6.9%	8.5%	9.9%	7.3%	8.1%
Corp bonds	1.3%	3.8%	2.6%	N/A	N/A	1.4%	1.5%	1.1%	N/A	N/A
Gov bonds	0.3%	2.2%	2.0%	N/A	N/A	0.8%	1.9%	-0.1%	N/A	N/A
Real estate	6.3%	6.6%	5.6%	N/A	8.5%	N/A	N/A	N/A	6.3%	N/A
Private equity	12.1%	9.8%	8.2%	7.9%	9.0%	N/A	6.6%	7.2%	8.5%	N/A
Hedge funds	5.9%	5.0%	4.2%	2.6%	2.8%	3.3%	3.9%	5.4%	5.0%	3.3%
Comm-odity	N/A	4.5%	2.1%	N/A	1.4%	4.3%	1.0%	5.7%	2.8%	3.6%

Table 21: Expected risk estimates from leading asset managers and consultants

Asset class	Blackrock	JP Morgan	BNY Mellon	Northern Trust	Morgan Stanley	Invesco	Schroders	State Street	Callan	Envestnet PMC
US equity	16.3%	14.3%	15.3%	14.4%	14.8%	18.7%	12.5%	15.0%	18.1%	15.2%
Emerging equity	20.6%	21.1%	20.8%	21.2%	21.1%	25.6%	12.0%	21.0%	25.7%	22.4%
Corp bonds	6.9%	6.0%	4.9%	N/A	N/A	8.7%	5.5%	4.3%	N/A	N/A
Gov bonds	5.5%	3.5%	2.8%	N/A	N/A	9.5%	5.4%	3.6%	N/A	N/A
Real estate	12.2%	11.1%	8.5%	N/A	8.4%	N/A	N/A	N/A	14.0%	N/A
Private equity	31.1%	20.2%	17.8%	16.9%	12.2%	N/A	17.9%	24.7%	27.8%	N/A
Hedge funds	8.1%	7.7%	5.7%	5.8%	5.3%	12.6%	3.5%	5.7%	8.7%	5.5%
Comm-odity	N/A	16.1%	14.2%	N/A	17.0%	21.8%	13.6%	15.1%	18.0%	16.5%

Table 22: Correlation estimates from JP Morgan

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.76	0.28	-0.31	0.53	0.73	0.67	0.45
Emerging equity	0.76	1	0.43	-0.2	0.42	0.8	0.69	0.6
Corp bonds	0.28	0.43	1	0.4	0.08	0.18	0.25	0.24
Gov bonds	-0.31	-0.2	0.4	1	-0.37	-0.49	-0.42	-0.14
Real estate	0.53	0.42	0.08	-0.37	1	0.49	0.46	0.38
Private equity	0.73	0.8	0.18	-0.49	0.49	1	0.77	0.58
Hedge funds	0.67	0.69	0.25	-0.42	0.46	0.77	1	0.55
Comm-odity	0.45	0.6	0.24	-0.14	0.38	0.58	0.55	1

Table 23: Correlation estimates from Callan

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.775	N/A	N/A	0.695	0.83	0.775	0.22
Emerging equity	0.775	1	N/A	N/A	0.625	0.765	0.72	0.2
Corp bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gov bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Real estate	0.695	0.625	N/A	N/A	1	0.6	0.525	0.2
Private equity	0.83	0.765	N/A	N/A	0.6	1	0.635	0.18
Hedge funds	0.775	0.72	N/A	N/A	0.525	0.635	1	0.21
Comm-odity	0.22	0.2	N/A	N/A	0.2	0.18	0.21	1

https://www.callan.com/wp-content/uploads/2020/01/Capital-Markets-Assumptions-2020-WebinarDeck.pdf

Table 24: Correlation estimates from BNY Mellon

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.75	0.19	-0.34	0.27	0.96	0.71	0.44
Emerging equity	0.75	1	0.35	-0.2	0.26	0.71	0.71	0.58
Corp bonds	0.19	0.35	1	0.66	0.08	0.16	0.32	0.18
Gov bonds	-0.34	-0.2	0.66	1	-0.09	-0.32	-0.21	-0.17
Real estate	0.27	0.26	0.08	-0.09	1	0.22	0.2	0.2
Private equity	0.96	0.71	0.16	-0.32	0.22	1	0.71	0.42
Hedge funds	0.71	0.71	0.32	-0.21	0.2	0.71	1	0.56
Comm-odity	0.44	0.58	0.18	-0.17	0.2	0.42	0.56	1

https://www.bnymellonwealth.com/assets/pdfs-strategy/10-year-capital-market-assumptions.-calendar-year-2020.pdf

Table 25: Correlation estimates from Morgan Stanley

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.52	N/A	N/A	0.23	0.6	0.59	0.11
Emerging equity	0.52	1	N/A	N/A	0.14	0.2	0.5	0.2
Corp bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gov bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Real estate	0.23	0.14	N/A	N/A	1	0.5	0.2	-0.03
Private equity	0.6	0.2	N/A	N/A	0.5	1	0.41	0.06
Hedge funds	0.59	0.5	N/A	N/A	0.2	0.41	1	0.17
Comm-odity	0.11	0.2	N/A	N/A	-0.03	0.06	0.17	1

https://graystone.morganstanley.com/graystone-consulting-farmington-hills-mi/documents/field/g/gr/graystone-consulting--farmington-hills--mi/Annual%20Update%20of%20our%20Capital%20Market%20Return%20Forecasts.pdf

Table 26: Correlation estimates from Northern Trust

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.78	N/A	N/A	N/A	0.8	0.85	N/A
Emerging equity	0.78	1	N/A	N/A	N/A	0.75	0.88	N/A
Corp bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gov bonds	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Real estate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Private equity	0.8	0.75	N/A	N/A	N/A	1	0.71	N/A
Hedge funds	0.85	0.88	N/A	N/A	N/A	0.71	1	N/A
Comm-odity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

https://www.capitalmarketassumptions.com/matrices/

Table 27: Correlation estimates from Invesco

	US equity	Emerging equity	Corp bonds	Gov bonds	Real estate	Private equity	Hedge funds	Comm-odity
US equity	1	0.7	0.33	0.17	N/A	N/A	0.7	0.28
Emerging equity	0.7	1	0.19	-0.05	N/A	N/A	0.52	0.35
Corp bonds	0.33	0.19	1	0.9	N/A	N/A	0.76	-0.02
Gov bonds	0.17	-0.05	0.9	1	N/A	N/A	0.7	-0.1
Real estate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Private equity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hedge funds	0.7	0.52	0.76	0.7	N/A	N/A	1	0.24
Comm-odity	0.28	0.35	-0.02	-0.1	N/A	N/A	0.24	1

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EDHEC*infra* Publications (2016-2020)

EDHECinfra Methdologies & Standards

- The Infrastructure Company Classification Standard (TICCS) - Updated March 2020
- Credit Risk Methodology - April 2020
- Infrastrcuture Index Methdology Standard - Updated March 2020
- Global Infrastructure Investment Data Standard - Updated March 2020
- Unlisted Infrastructure Valuation Methodology - A Moderm Approach to Measuring Fair Value in Illiquid Infrastructure Investments - Updated March 2020

Selected EDHEC Publications

- Amenc, N. & F. Blanc-Brude. "The Cost of Capital of Motorway Concessions in France - A Modern Approach to Toll Regulation" (September 2020)
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For more information, please contact:
Tina Chua on +65 6438 0030
or e-mail: tina.chua@edhec.edu

EDHEC Infrastructure Institute
EDHEC Asia-Pacific
One George Street - #15-02
Singapore 049145
Tel.: +65 6438 0030

edhec.infrastructure.institute