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Searching for a listed infrastructure asset class using mean–variance spanning

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Abstract This study examines the portfolio-diversification benefits of listed infrastructure stocks. We employ three different definitions of listed infrastructure and tests of mean–variance spanning. The evidence shows that viewing infrastructure as an asset class is misguided. We employ different schemes of infrastructure asset selection (both traditional asset classes and factor exposures) and discover that they do not provide portfolio-diversification benefits to existing asset allocation choices. We also find that defining and selecting infrastructure investments by business model as opposed to industrial sectors can reveal a very different investment profile, albeit one that improves the mean–variance efficient frontier since the global financial crisis. This study provides new insights into defining and benchmarking infrastructure equity investments in general, as well as into the extent to which public markets can be used to proxy the risk-adjusted performance of privately held infrastructure investments.

Keywords Infrastructure investment · Mean–variance spanning · Asset allocation · Benchmarking

JEL Classification G12 · G23 · G32 · O18

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1 Introduction

In this paper, we ask the question: Does focusing on listed infrastructure stocks create diversification benefits previously unavailable to large investors already active in public markets?

This question arises from what we call the "infrastructure investment narrative" (Blanc-Brude 2013), which is a set of beliefs commonly held by investors about the investment characteristics of infrastructure assets.

According to this narrative, the "infrastructure asset class" is less exposed to the business cycle because of the low price elasticity of infrastructure services, implying improved diversification. Furthermore, the value of these investments is expected to be mostly determined by income streams extending far into the future and should thus be less impacted by current events, suggesting a degree of downside protection. According to this narrative, infrastructure investments may provide diversification benefits to investors since they are expected to exhibit low return covariance with other financial assets. In other words, infrastructure investments are expected to exhibit unique characteristics.

Empirically, there are at least three reasons why this view requires further examination:

1. Most research on infrastructure uses public equity markets to infer findings for the whole infrastructure investment universe, but there is no robust and conclusive evidence to support this approach;
2. Index providers have created dedicated indices focusing on this theme and a number of active managers propose to invest in listed infrastructure arguing that it constitutes an asset class in its own right and is worthy of an individual allocation;
3. Listed infrastructure stocks are often used by investors to proxy investments in privately held (unlisted) infrastructure, but the adequacy of such proxies remains untested.

The existence of a distinctive *listed infrastructure effect* in investors' portfolios would support these views. However, if this effect cannot be found, there is little to expect from listed infrastructure equity from an asset allocation (risk/reward optimization) perspective and maybe even less to learn from public markets about the expected performance of unlisted infrastructure investments.

In this paper, we test the impact of adding 22 different proxies of public infrastructure stocks to the portfolio of a well-diversified investor using mean–variance spanning tests. We focus on three definitions of "listed infrastructure" as an asset selection scheme:

1. A "naïve" rule-based filtering of stocks based on industrial sector classifications and percentage income generated from predefined infrastructure sectors (nine proxies);
2. Existing listed infrastructure indices designed and maintained by index providers (12 proxies);
3. A basket of stocks offering a pure exposure to several hundred projects that correspond to a well-known form of infrastructure investment. These projects are

defined, in contrast with the two previous cases, in terms of long-term public–private contracts, not industrial sectors (one proxy).

In what follows, we show that the existence of diversification benefits is dependent on how infrastructure is defined and understood as an asset selection scheme.

Overall, we find no *persistent* evidence to support the claims that listed infrastructure provides diversification benefits. In other words, any "listed infrastructure" effect was already spanned by a combination of capital–market instruments over the past 15 years in global, US, and UK markets.

We show that listed infrastructure, as it is traditionally defined (by SIC code and industrial sector), is not an asset class or a unique combination of market factors. Indeed, it cannot be distinguished from existing exposures in investors' portfolios. We also show that an alternative definition of infrastructure focusing on the relationship-specific, and therefore contractual, nature of the infrastructure business can help identify exposures that have at least the potential to persistently improve portfolio diversification.

The rest of this paper is structured as follows. Section 2 briefly reviews existing research on the performance of listed infrastructure. Section 3 details our approach, while Sects. 4 and 5 present our choice of methodology and data, respectively. The results of the analysis are reported in Sect. 6. Section 7 discusses our findings and their implications for better defining and benchmarking infrastructure equity investments.

2 Literature review

In Fabozzi and Markowitz (2011, p. 16), asset classes are defined as homogeneous investments with comparable characteristics driven by similar factors, including a common legal or regulatory structure, thus correlating highly with each other. Fabozzi and Markowitz (2011) state that as a result of this definition, the combination of two or more asset classes should provide diversification benefits. Two distinct asset classes should exhibit low return covariance with each other.

The question of whether listed infrastructure is an asset class and is a good proxy for a broader universe of privately held infrastructure equity has been discussed in previous research. The approach taken in the literature has been to define infrastructure in terms of industrial categories since roads and airports can seem rather similar businesses compared with automotive factories or financial services. Given the definition above, they can be expected to form a relatively homogeneous group of stocks, indicating a potential asset class.

Existing studies can be organized in two groups. First is literature that employs rule-based stock selection schemes focusing on what is traditionally understood as "infrastructure," that is, a collection of industrial sectors. The second group is comprised of papers that employ listed infrastructure indices created by a number of index providers.

The first group of studies examines stocks that are classified under a set list of infrastructure *activities* and derive a certain proportion of their income from these activities.[1]

[1] See Newell and Peng (2007, 2008), Finkenzeller et al. (2010), Newell et al. (2009), Rothballer and Kaserer (2012), and Bitsch (2012).

The findings from these studies suggest considerable heterogeneity in "listed infrastructure." Newell and Peng (2007) report that listed Australian infrastructure exhibits *higher returns, but also higher volatility* than equity markets. They find higher Sharpe ratios than the market and low but growing correlations over time with market returns. Finkenzeller et al. (2010) find similar results. The work of Newell and Peng (2008) finds that in the USA, infrastructure (ex-utilities) underperforms stocks and bonds over the period from 2000 to 2006, while utilities outperform the market. Rothballer and Kaserer (2012) find that infrastructure stocks exhibit *lower market risk than equities in general but not lower total risk*, that is, they find high idiosyncratic volatility. They also report significant heterogeneity in the risk profiles of different infrastructure sectors, with an average beta of 0.68, but with variation between sectors. For the utility, transport, and telecom companies, the average betas were 0.50, 0.73, and 1.09, respectively.[2] Bitsch (2012) finds that infrastructure vehicles are priced using a high-risk premium in part because of complex and opaque financial structuring, information asymmetries with managers, and regulatory and political risks.

These findings are in line with the results of several industry studies suggesting that the volatility of infrastructure indices is on par with equities and real estate, but that market correlation is relatively low (Colonial First State Asset Management 2009; RREEF 2008). The conclusions from this strand of the literature are limited. Infrastructure stocks are found to have higher Sharpe ratios in some cases, but the statistical significance of this effect is never tested. Overall, rule-based infrastructure stock selection schemes lead to either anecdotal (small sample) or heterogeneous results, which do not support the notion of an independent asset class.

2.1 Ad hoc listed infrastructure indices

A second group of studies uses infrastructure indices created by index providers such as Dow Jones, FTSE, MSCI, and S&P, as well as financial institutions such as Brookfield, Macquarie, and UBS. These indices are not fundamentally different from the approach described above. They use asset selection schemes based on slightly different industrial definitions of what qualifies as infrastructure and apply a market-capitalization weighing scheme. They are ad hoc as opposed to rule-based because index providers pick and choose which stocks are included in each infrastructure index. Their weighing scheme may also create concentration issues, since they are likely to include very large utilities relative to other firms active in the infrastructure sector, regardless of how it is defined.

Using such indices, Bird et al. (2014) and Bianchi et al. (2014) find that infrastructure exhibits returns, correlation, and tail risk similar to that of the stock market, with a marginally higher Sharpe ratio, driven by what could be described as a utility tilt. Other studies on the performance of infrastructure indices by Peng and Newell (2007),

[2] Using the same sample as Rothballer and Kaserer (2012), Rödel and Rothballer (2012) examine the inflation-hedging ability of infrastructure. They find no evidence to suggest infrastructure exhibits a greater ability to hedge inflation risks than do listed equities. Even restricting their sample to firms with assumed strong monopoly characteristics fails to yield a statistically significant result.

Finkenzeller et al. (2010), Dechant and Finkenzeller (2013), and Oyedele et al. (2014) also report potential diversification benefits. However, none examine whether these are statistically or economically significant. For example, Peng and Newell (2007) and Oyedele et al. (2014) compare Sharpe ratios but provide no statistical tests to support their conclusions.

Idzorek and Armstrong (2009) provide the only study of the role of listed infrastructure in a portfolio context. The authors create an infrastructure index by combining existing industry indices. Using three versions of their composite index (low, medium, and high utilities), and consistent with previous papers, they report that over the 1990–2007 period, infrastructure returns were similar to those of US equities but with slightly less risk. Finally, using the capital asset pricing model (CAPM) to create a forward-looking model of expected returns including an infrastructure allocation, Idzorek and Armstrong (2009) find that adding infrastructure does not lead to a meaningful improvement in the efficient frontier.

2.2 Limitations of existing research

The existing literature has not examined whether different types of listed infrastructure investments are already spanned in the portfolio of a typical investor. As a result, it remains unclear whether a focus on infrastructure-related stocks can create additional diversification benefits for investors. Nor is it clear whether infrastructure is a new combination of investment factor exposures.

In the rest of this paper, we empirically test whether infrastructure stocks, selected according to their industrial classification, provide diversification benefits to investors. Furthermore, following the argument in Blanc-Brude (2013), we examine a different definition of infrastructure, focusing on the "business model" as determined by the role of long-term contracts in infrastructure projects. Next, we describe our approach in more detail.

3 Approach

We propose to test the portfolio characteristics of listed infrastructure equity under the three different definitions of what constitutes infrastructure given in Sect. 1.

The first two are "naïve" rule-based filtering of stocks based on industrial sector classifications and listed infrastructure indices maintained by index providers. These first two proxies focus on the "real" characteristics of the relevant capital projects. They bundle together assets that may all be related to large structures of steel and concrete but may also have radically different risk profiles from an investment viewpoint.

Hence, we also look at a basket of stocks offering a pure exposure to projects that correspond to a specific long-term contract but not to any specific industrial sectors.

This last case thus captures a specific infrastructure "business model." We identify a number of stocks that happen to create a useful *natural experiment*: These are the publicly traded shares of investment vehicles that are solely involved in buying and holding the equity of infrastructure projects engaged in PFI (private finance initiative) projects in the UK and, to a lesser extent, their equivalents in Canada, France, and the rest of the OECD (Organisation for Economic Co-operation and Development).[3]

The firms we identify are listed on the London Stock Exchange, and they buy and hold the equity and shareholder loans (quasi-equity) of hundreds of these PFI project companies. They distribute dividends on a regular basis. They are, in effect, a listed basket of PFI equity (with no additional leverage) and, as such, represent a unique proxy for one model of private infrastructure investment.

We can expect the cash flows of these firms to be highly predictable, uncorrelated with markets and the business cycle, albeit highly correlated with the UK RPI index. In other words, we can expect to see some evidence of the "infrastructure investment narrative" discussed earlier that has so far eluded studies of infrastructure stocks defined by their SIC code.

3.1 Testing asset classes or factors?

Using these three alternative approaches to define infrastructure investment, we employ the mean–variance spanning test designed by Huberman and Kandel (1987) to determine whether adding a listed infrastructure bucket to an existing investment portfolio significantly increases diversification opportunities.

If the answer is in the affirmative, this result implies a degree of "asset class-ness" of infrastructure stocks, since their addition to a reference portfolio effectively shifts the mean–variance efficient frontier (to the left) and can create new diversification opportunities for investors. Furthermore, we define the reference portfolio used to test the mean–variance spanning properties of listed infrastructure either in terms of traditional asset classes or investment factors.

Indeed, the notion of asset class has been losing its relevance in investment management since the financial crisis of 2008, when existing asset class-based allocations failed to provide diversification (e.g., Ilmanen and Kizer 2012).

Factor-based asset allocations aim to identify the persistent dimensions of financial assets that best explain (and predict) their performance instead of assuming that assets belong to distinctive categories because they have different names.[4]

[3] PFI projects consist of dedicated project firms entering into long-term contracts with the public sector to build, maintain, and operate public infrastructure facilities according to a pre-agreed service output specification. As long as these firms deliver the projects and associated services for which they have contracted, on time and according to specifications, the public sector is committed to pay a monthly or quarterly income to the firm according to a pre-agreed schedule for multiple decades. In the UK, the long-term contract between the public and private parties also stipulates that this "availability payment" is adjusted to reflect changes in the retail Price Index (RPI). Each project company is a special-purpose vehicle created solely to deliver an infrastructure project and financed on a nonrecourse basis with sponsor equity, shareholder loans, and senior debt.

[4] Such factors include the Fama and French (1992) size and value premiums, the term and default premiums (Fama and French 1993), and the momentum anomaly identified by Jegadeesh and Titman (1993). Bender et al. (2010) show that these premiums are uncorrelated with each other and that they increase returns and reduce portfolio volatility over traditional asset class allocations. Likewise, when comparing the diversification benefits of factor-based allocations to alternative assets, Bird et al. (2013) find that factor approaches tend to outperform alternative asset classes. For recent and in-depth analyses of factor investing, see Amenc et al. (2014).

Thus, we include both a traditional asset allocation based on asset classes and a factor-based allocation to examine the diversification benefits of listed infrastructure under the three definitions so as to test whether listed infrastructure is indeed an asset class or, alternatively, a unique combination of investment factors.

3.2 Testing persistence

Finally, we test the existence of a *persistent* effect of listed infrastructure on a reference portfolio by splitting the observation period in two, from 2000 to 2008 and from 2009 to 2014, to test for the impact of the 2008 reversal of the credit cycle, aka the global financial crisis (GFC). In Sect. 6, we report results for the whole sample period, as well as for two subsample periods denoted as pre- and post-GFC periods.

In the case of the PFI portfolio, our data begin in 2006, and so we also divide the sample in 2011, which marks the time of the Eurozone debt crisis and the launch of quantitative easing policies by the Bank of England.

In the next section, we discuss the mean–variance spanning methodology used in the remaining sections of this paper.

4 Methodology

In a mean–variance framework, the question of whether infrastructure provides diversification benefits is equivalent to asking whether investors are able to improve their optimal mean–variance frontier by including infrastructure stocks in an existing reference portfolio.

This question can be answered using the mean–variance spanning test described by Huberman and Kandel (1987), which examines whether the efficient frontier is improved when including new assets. If the mean–variance frontier, inclusive of the new assets, coincides with that already produced by the reference assets, the new assets can be considered to be already spanned by the existing portfolio, that is, no new diversification benefit is created. Conversely, if the existing mean–variance frontier is shifted to the left in the mean/variance plane by the addition of the new asset, then investors have improved their investment-opportunity set.

This approach has been used to examine the diversification benefits of different asset classes. For instance, Petrella (2005) and Eun et al. (2008) employ this methodology to examine the diversification benefits of small-cap stocks. Likewise, Kroencke and Schindler (2012) examine the benefits of international diversification in real estate using mean–variance spanning, while Chen et al. (2011) examines the diversification benefits of volatility. However, to date, the approach has not been used in the literature on listed infrastructure.

Mean–variance spanning is a regression-based test that assumes that there are K reference assets as well as N test assets. In Huberman and Kandel (1987), there is a linear relationship between test and reference assets so that:

$$R_{2t} = \alpha + \beta R_{1t} + \varepsilon_t \tag{1}$$

with $t = 1, \dots T$ periods and $R1$ representing a $T \times K$ matrix of excess realized returns of the K benchmark assets. $R2$ represents a $T \times N$ matrix of realized excess returns of the N test assets. β is a $K \times N$ matrix of regression factor loadings and ε is a vector of the regression error terms.

The null hypothesis is that existing assets already span the new assets. This implies that the α of the regression in Eq. (1) is equal to 0, while the sum of the βs equals 1. As a result, the null hypothesis assumes that a combination of the existing benchmark assets is capable of replicating the returns of the test assets with a lower variance.

Chen et al. (2011) describe the null hypothesis as:

$$H_{0S} = \alpha = 0, \quad \delta = 1 - \beta 1_K = 0 \tag{2}$$

where α is the regression intercept coefficient and β is the matrix of factor loadings.

As this analysis is only examining the case where $N = 1$, the test statistic is given by:[5]

$$HK = \left(\frac{1}{V - 1}\right)\left(\frac{T - K - 1}{2}\right) \tag{3}$$

where V is the ratio of the determinant of the maximum likelihood estimator of the error covariance matrix of the model assuming that there is no spanning of the efficient frontier (otherwise known as the unrestricted model) to that of the determinant of the maximum likelihood estimator of the model that assumes spanning occurs (known as the restricted model).

T is the number of return observations; K is the number of benchmark assets included in the study. The HK variable is a Wald test statistic and follows an F-distribution with $(2, T - K - 1)$ degrees of freedom.

Kan and Zhou (2012) developed a two-stage test to examine whether the rejection of the Huberman and Kandel (1987) null hypothesis is due to differences in the tangency or the global minimum variance as a result of the addition of new assets. The first step of the Kan and Zhou (2012) test examines whether $\alpha = 0$.

If the null is rejected at this stage, the two tangency portfolios comprising the benchmark assets, and the benchmark and new assets, respectively, are statistically different.

The second stage of the Kan and Zhou (2012) test examines whether $\delta = 0$ conditional on $\alpha = 0$. If the null hypothesis is rejected, the global minimum variance of the test portfolio and the benchmark portfolios are statistically different (for a discussion, see Chen et al. 2011).

In this paper, we incorporate both the Huberman and Kandel (1987) and Kan and Zhou (2012) tests to investigate where infrastructure can provide portfolio-diversification benefits.[6]

Next, we describe the data employed in this study.

[5] Kan and Zhou (2012) state that if $N \geq 2$, the appropriate formation of the test statistic is given as $HK = \left(\frac{1}{V^{\frac{1}{2}} - 1}\right)\left(\frac{T-K-1}{2}\right)$.

[6] As another robustness check, we employ the Gibbons et al. (1989) test of portfolio efficiency. The results are similar to the mean–variance spanning test results presented in this paper. The results are available upon request.

5 Data

This section describes the datasets used to build test infrastructure portfolios and reference portfolios to which to apply the mean–variance spanning methodology described previously.

Sections 5.1, 5.2, and 5.3 describe listed infrastructure proxies designed with sector-based asset selection rules, index provider data, and the PFI portfolio, respectively. Section 5.4 describes the reference portfolios, with the summary statistics reported in Appendices A and B. All returns and standard deviations reported in this section are annualized from monthly data.

5.1 Test assets—listed infrastructure companies

5.1.1 Asset selection

The first asset selection scheme represents the "naïve" definition of infrastructure equity investment and follows the methodology described by Rothballer and Kaserer (2012), following broad industry definitions to determine infrastructure-related stocks.[7]

There are 5757 possible securities thus identified as infrastructure related. Next, only stocks for which the majority of the revenue was obtained from sectors corresponding to infrastructure activities are kept in the sample. A minimum market capitalization of USD 500 million is also required to be included in the sample. This yields 1290 firms with at least 50% of their income from infrastructure activities.[8] Setting a minimum infrastructure sector revenue threshold to 75 and 90% yields 650 and 554 stocks, respectively.[9] USD price and total returns are from Datastream using the methodology described in Ince and Porter (2006).[10] The firms thus identified comprise at most 12, 7, and 6.5% of the MSCI World market value as of December 31, 2014, for the 50, 75, and 90% revenue thresholds, respectively.

[7] The SIC and GIC codes used to identify infrastructure are available upon request.

[8] The minimum revenue by infrastructure type is reported by SIC or GIC code by Worldscope. This is a crude measure, as it relies on the continuous updating of the revenue codes by Worldscope, as well as on the assumption that GIC or SIC codes represent infrastructure activities.

[9] The number of firms identified as well as their geographic and industry distributions are available upon request.

[10] Extreme monthly returns are identified following Ince and Porter (2006) and set to a missing value. Ince and Porter (2006) set an arbitrary cutoff of 300% for extreme monthly returns. If $R1$ or $Rt-1$ is greater than 300% and $(1+R1)/(1+Rt-1)-1$ is less than 50%, then $R1$ or $Rt-1$ are set to missing. Furthermore, following Rothballer and Kaserer (2012), 18 months of nonzero returns are required for the stock to be included in the portfolios. Any Datastream-padded price is removed by requesting X(P#S) $U, which returns null values when Datastream does not have a record and any nonequity item is removed by requiring the TYPE description in Datastream to be equal to EQ.

Table 1 Descriptive statistics of the naïve infrastructure stock selection scheme, 2000–2014

Price returns Panel A: 50% revenue levels	Telecom 50%	Transport 50%	Utilities 50%	MSCI World
Price return	−0.0839	0.0195	−0.0049	0.0124
Risk	0.1785	0.1538	0.1518	0.1584
SR	−0.4957	0.0939	−0.0652	0.0465
Worst drawdown	−0.0839	0.0195	−0.0049	0.0124
Panel B: 75% revenue levels	Telecom 75%	Transport 75%	Utilities 75%	MSCI World
Price return	−0.0919	0.0683	0.003	0.0124
Risk	0.1848	0.1983	0.1331	0.1584
SR	−0.5224	0.3176	−0.015	0.0465
Worst drawdown	−0.0919	0.0683	0.003	0.0124
Panel C: 90% revenue levels	Telecom 90%	Transport 90%	Utilities 90%	MSCI World
Price return	−0.0854	0.0422	0.0016	0.0124
Risk	0.1746	0.1802	0.1327	0.1584
SR	−0.5153	0.2052	−0.0253	0.0465
Worst drawdown	−0.0854	0.0422	0.0016	0.0124
Total returns Panel D: 50% revenue levels	Telecom 50%	Transport 50%	Utilities 50%	MSCI World
Tot. return	−0.0518	0.0479	0.0277	0.0364
Risk	0.1798	0.1517	0.1529	0.1587
SR	−0.3147	0.2815	0.1475	0.1969
Worst drawdown	−0.0518	0.0479	0.0277	0.0364
Panel E: 75% revenue levels	Telecom 75%	Transport 75%	Utilities 75%	MSCI World
Tot. return	−0.0568	0.1087	0.0393	0.0364
Risk	0.1845	0.1972	0.134	0.1587
SR	−0.3335	0.5234	0.255	0.1969
Worst drawdown	−0.0568	0.1087	0.0393	0.0364

5.1.2 Descriptive statistics

For market-cap-weighted portfolios of infrastructure stocks, defined according to the industry-based scheme described above, we report, in Table 1, annualized returns, standard deviation and Sharpe ratios, and the maximum drawdown statistics for the period 2000–2014 for price and total returns.[11]

Note that the reference market index should not be difficult to beat. While market-cap-weighted indices are a useful point of reference, they have been shown to be highly

[11] The maximum drawdown statistic is measured as a percentage of maximum cumulative monthly return in the sample period.

Table 1 continued

Panel F: 90% revenue levels	Telecom 90%	Transport 90%	Utilities 90%	MSCI World
Tot. return	−0.0508	0.088	0.0384	0.0364
Risk	0.1762	0.1791	0.1332	0.1587
SR	−0.3151	0.4613	0.2493	0.1969
Worst drawdown	−0.0508	0.088	0.0384	0.0364

Telecom, Transport, and Utilities are portfolios of stocks that earn a minimum revenue level from activities related to SIC or GIC codes recognized as telecommunications, transport, and utilities industries, respectively. Panels A, B, and C display the summary statistics for the price returns for portfolios created according to the 50, 75, and 90% minimum revenue levels, respectively. Panels D, E, and F display the summary statistics for the total returns for portfolios created according to the 50, 75, and 90% minimum revenue levels, respectively. The return is the annualized average monthly return from January 2000 to December 2014. All returns are USD returns calculated on an unhedged basis. Risk is the annualized monthly standard deviation of returns from January 2000 to December 2014. SR is the Sharpe ratio calculated with the average yield of the US 1-month Treasury bill as the risk-free rate proxy. Worst drawdown is the maximum drawdown statistic, measured as a percentage of the maximum cumulative return, i.e., "peak equity."

inefficient in previous research (see Amenc et al. 2010).[12] Nevertheless, the listed infrastructure portfolios obtained above do not necessarily offer better risk-adjusted performance than this relatively unambitious baseline.

We observe that irrespective of the revenue cutoffs employed to create the infrastructure portfolios, the telecom sector continually produces poor returns. It appears that this sector has not recovered from the bursting of the technology bubble in the early 2000s. This suggests that infrastructure sectors experience a high degree of cyclicality, as well as a complete absence of persistence. Transportation fares better, with higher Sharpe ratios than the market index under both the price return and total return measures. Drawdown risk is typically higher than the market return for price and total returns, as shown in Table 1. During the sample period, utilities outperform the broad market only from a total return perspective.

Next, we describe our second test asset, a combination of rule-based and ad hoc stock selection schemes created by index providers.

5.2 Test assets—ad hoc listed infrastructure indices

5.2.1 Asset selection

The basic requirements for being included in listed infrastructure indices created by index providers are not very different from the naïve selection scheme described above. They include:

[12] The MSCI World Index is a free-float-adjusted market-capitalization-weighted index comprising 1631 mid-size and large capitalization stocks across 23 developed-country equity markets. MSCI states that the index comprises 85% of the free-float-adjusted market capitalization of each country covered. The index is updated quarterly with annual revisions to the investable universe and the removal of stocks with low liquidity.

1. being part of a broader index universe (usually that of the infrastructure universe of the index provider); and
2. a minimum amount of revenue derived from infrastructure activities.

However, minimum revenue requirements and the definition of infrastructure activities vary between index providers, adding what could amount to active views to a rule-based scheme.

We test two groups of listed infrastructure indices: a set of global indices and one designed to represent the US market only. Global indices provide a direct comparison with the naïve approach described above, while a US-only perspective allows more controls and granularity when designing a reference portfolio of asset classes or factors to test the mean–variance spanning of listed infrastructure indices.

Global infrastructure indices

The indices included in this sample are listed below; their descriptive statistics are presented in Sect. 5.2.2. This study includes seven global infrastructure indices and four US infrastructure indices. The global infrastructure indices are:[13]

– Dow Jones Brookfield Global Infrastructure Index;
– FTSE Macquarie Global Infrastructure Index;
– FTSE Global Core Infrastructure;
– MSCI World Infrastructure Index;
– MSCI ACWI Infrastructure Capped;
– UBS Global Infrastructure and Utilities; and
– UBS Global 50/50 Infrastructure and Utilities.

The universe thus recognized by index providers is not very large, with only the MSCI World Infrastructure and MSCI ACWI Global Infrastructure representing more than 10% of the value of the MSCI World Index.

US infrastructure indices

The US infrastructure indices included in this study are:

– FTSE Macquarie USA Infrastructure Index;
– MSCI US Infrastructure Index;
– MSCI USA Infrastructure 20/35 Capped Index; and
– Alerian MLP Infrastructure Index.

5.2.2 Descriptive statistics

Global infrastructure indices

Table 2 shows that most infrastructure indices exhibit higher Sharpe ratios than the reference market index (MSCI World). The Dow Jones Brookfield Global Infrastructure Index exhibits the highest average annualized returns and Sharpe ratio for the sample period. This performance is in contrast to that of the MSCI World Infrastructure Index, which exhibits negative performance on a price return basis. Table 2 suggests that drawdown risk is very similar between infrastructure indices and the broad market, with the exception of the Brookfield and MSCI ACWI indices.

[13] A brief summary of the indices is available upon request.

Table 2 Descriptive statistics for the global infrastructure indices for the period 2000–2014

	BF	SP	FTSEM	FTSEC	MSCI	MSCIA	UBS	UBS50	MSCIW
Price returns									
Return	0.112	0.072	0.043	0.063	−0.020	0.025	0.046	0.055	0.012
Risk	0.132	0.153	0.138	0.115	0.145	0.105	0.119	0.145	0.158
SR	0.807	0.436	0.273	0.507	−0.171	0.192	0.347	0.341	0.047
Worst drawdown	0.476	0.551	0.456	0.374	0.660	0.424	0.447	0.505	0.554
Total returns									
Return	0.147	0.116	0.083	0.099	0.019	0.061	0.082	0.091	0.036
Risk	0.132	0.153	0.138	0.114	0.146	0.105	0.119	0.145	0.159
SR	1.070	0.725	0.561	0.820	0.092	0.532	0.644	0.588	0.197
Worst drawdown	0.452	0.527	0.432	0.348	0.640	0.395	0.426	0.484	0.537

BF is the Dow Jones Brookfield Global Infrastructure Index, SP is Standard and Poor's Global Infrastructure Index, FTSEM is the FTSE Macquarie Global Infrastructure Index, FTSEC is the FTSE Global Core Infrastructure Index, MSCI is the MSCI World Infrastructure Index, MSCIA is the MSCI ACWI Infrastructure Capped, UBS is the UBS Global Infrastructure and Utilities, UBS 50 is the UBS Global 50/50 Infrastructure and Utilities Index, and MSCIW is the MSCI World Index. Return is the annualized average monthly return from the index commencement date to December 2014. Risk is the annualized monthly standard deviation of returns from the index commencement date to December 2014. SR is the Sharpe ratio, calculated with the average yield of the US 1-month Treasury bill as the risk-free rate proxy. Worst drawdown is the maximum drawdown statistic, measured as a percentage of the maximum cumulative return, i.e., "peak equity." All returns are USD returns calculated on an unhedged basis

US infrastructure indices
In the case of US-only indices, the MSCI and FTSE indices reported in Table 3 do not appear too different from the broad market index (here the Russell 3000), but the Alerian MLP Index, which captures an underlying business model focused on dividend distributions, exhibits very different characteristics.

5.3 Test assets-listed baskets of contracted infrastructure

Projects the PFI portfolio consists of

1. HSBC Infrastructure Company Ltd (HICL);
2. John Laing Infrastructure Fund Ltd (JLIF);
3. GCP Infrastructure Ltd (GCP);
4. International Partnerships Ltd (INPP); and
5. Bilfinger Berger Global Infrastructure Ltd (BBGI).

As discussed, these firms are solely occupied with buying and holding the equity and quasi-equity of PFI (private finance initiative) project companies in the UK and similar countries. The project companies they invest in are mostly involved in delivering so-called availability-payment infrastructure projects, by which the public sector pays a pre-agreed income to the project firm on a regular basis in exchange for the construction/development, maintenance, and operation of a given infrastructure project, given a pre-agreed output specification, for several decades.

Table 3 Descriptive statistics for annualized price and total returns of US infrastructure stock indices, 2000–2014

	AMLP	FTSEM	MSCI	MSCISC	R3000
Price returns					
Price return	0.130	0.063	−0.016	0.024	0.029
Risk	0.166	0.448	0.147	0.138	0.157
SR	0.748	0.130	−0.141	0.133	0.155
Worst drawdown	0.492	0.956	0.633	0.448	0.527
Total returns					
Price return	0.213	0.067	0.021	0.055	0.048
Risk	0.170	0.448	0.148	0.138	0.157
SR	1.219	0.137	0.106	0.361	0.274
Worst drawdown	0.431	0.956	0.609	0.423	0.512

AMLP is the Alerian MLP Infrastructure Index, FTSEM is the FTSE Macquarie USA Infrastructure Index, MSCI is the MSCI US Infrastructure Index, MSCISC is the MSCI USA Infrastructure 20/35 Capped Index, and R3000 is the Russell 3000 Index. Return is the annualized average monthly return from January 2000 to December 2014. Risk is the annualized monthly standard deviation of returns from January 2000 to December 2014. SR is the Sharpe ratio, calculated with the average yield of the US 1-month Treasury bill as the risk-free rate proxy. Worst drawdown is the maximum drawdown statistic, measured as a percentage of the maximum cumulative return, i.e., “peak equity”

These PFI project companies do not engage in any other activity during their lifetime and only deliver the contracted infrastructure and associated services while repaying their creditors and investors. As such, they give access to a pure infrastructure project cash flow, representative of the underlying nature of the PFI business model.

The firms in the PFI portfolio can be considered useful proxies for a portfolio of PFI equity investments. While the project companies are typically highly leveraged, the firms in the PFI portfolio do not make a significant use of leverage. Hence, as a group, they can be considered as representative of a listed basket of PFI equity stakes.

5.3.1 Descriptive statistics

Table 4 suggests that the PFI portfolio possesses different characteristics than the other listed infrastructure portfolios examined to this point. Its Sharpe ratio is high and its maximum drawdown is much lower than the market reference (here the FTSE All Shares). Indeed, the maximum drawdown for the PFI portfolio is also much lower than the FTSE Macquarie Europe Infrastructure Index. The combination of high-risk-adjusted performance with low drawdown risk is particularly striking in the total return case.

5.4 Reference assets

As discussed above, we use two types of reference allocations to test the impact of adding listed infrastructure to an investor’s universe, an asset class-based allocation

Table 4 Descriptive statistics for annualized price and total returns of the PFI portfolio, an infrastructure index, and the market index, 2006–2014

	PFI portfolio	FTSE all shares	Macquarie infra Europe
Price returns			
Price return	0.048	0.027	−0.007
Risk	0.093	0.182	0.181
SR	0.460	0.121	−0.065
Max. DD	0.240	0.450	0.500
Total returns			
Tot. return	0.101	0.065	0.046
Risk	0.082	0.172	0.184
SR	1.171	0.345	0.224
Max. DD	0.150	0.410	0.370

PFI Portfolio is the equal-weighted return of the PFI stocks listed on the London Stock Exchange. Return is the annualized average monthly return from 2006 to December 2014. Risk is the annualized monthly standard deviation of returns from 2006 to December 2014. SR is the Sharpe ratio, calculated with the average yield of the UK 1-month Treasury bill as the risk-free rate proxy. Max. DD is the maximum drawdown statistic, measured as a percentage of the maximum cumulative return, i.e., "peak equity." All returns are annualized monthly price and total returns computed in local currency (GBP) and sourced from Datastream

and a factor-based allocation. All the summary statistics for the reference assets are given in Tables 13 and 14 in the appendix.

5.4.1 Global asset class-based reference portfolio

A "well-diversified investor" in the traditional, albeit imprecise, meaning of the term can be expected to hold a number of different asset classes, including:

- Global fixed interest proxied by JP Morgan Global Aggregate Bond Index;
- Commodities proxied by the S&P Goldman Sachs Commodity Index;
- Real estate proxied by MSCI World Real Estate Index;
- Hedge funds proxied by the Dow Jones Credit Suisse Hedge Fund Index; and
- OECD and emerging market equities proxied by MSCI World and MSCI Emerging Market Indices, respectively.

One potential issue with employing indices as a reference asset is the possibility of double counting infrastructure stocks in both the reference and test assets. This has the potential of biasing the mean–variance spanning tests against finding an improvement in the investment-opportunity set. Ideally, removing any infrastructure like stocks from the reference assets would solve the problem of double counting; however, the circulation of index-constituent lists is too limited to allow this.

However, the MSCI World Index (MSCI 2014) states that as of November 2014, the utilities and telecom industries comprise 3.32 and 3.46% while the industrial sector comprises 10.89% and the share of infrastructure in industrials (e.g., railway) is small.

Although it would be preferable to exclude the infrastructure stocks from the MSCI World, we do not know the constituents, so this cannot be done. However, given the low weighting, it is not likely that any results will be biased against the infrastructure stocks. We conclude that not isolating infrastructure stocks from our reference assets will not materially influence the conclusions of this study.

The price and total returns for the reference asset portfolios are reported in Panel A of Table 13. The hedge fund index reports the highest price returns, at 0.062 for the period 2000 to 2014, whereas the OECD stocks report the lowest returns, at −0.001. The hedge fund proxy also reports the lowest standard deviation of returns; commodities report the highest. As a result, the hedge fund proxy reports the highest Sharpe ratio and the OECD stocks report the lowest.

The total returns of the asset class proxies reveal a similar finding. The hedge fund proxy reports the highest returns, lowest standard deviation, and highest Sharpe ratio. Commodities report the lowest returns and highest standard deviation and, as a result, the lowest Sharpe ratio for the sample period.

5.4.2 US asset class reference portfolio

A typical US-based reference portfolio built using traditional asset classes would include:

- Government bonds proxied by the Barclays Govt Aggregate Index;
- Corporate bonds represented by the Barclays US Aggregate Index;
- High-yield bonds with the Barclays US Corporate High Yield;
- Real estate, as per the US DataStream Real Estate Index;
- Hedge funds represented by the Dow Jones Credit Suisse Hedge Fund Index;
- Commodities proxied by the S&P Goldman Sachs Commodity Index;
- US equities captured by the Russell 3000;[14] and
- World equities represented by the MSCI World ex-US.

Panel B of Table 13 displays the summary statistics for the US asset class reference portfolios. For the price returns the hedge fund proxy exhibits the highest returns; high-yield bonds exhibit the lowest. Corporate bonds report the lowest standard deviation; commodities report the highest. Finally, real estate reports the highest Sharpe ratio during the sample period and high-yield bonds report the lowest.

For the total returns, again hedge funds exhibit the highest returns, whereas commodities exhibit the lowest. Corporate bonds exhibit the lowest standard deviation, and commodities again exhibit the highest. When total returns are considered, corporate bonds have the highest Sharpe ratio; commodities have the lowest.

[14] The Russell 3000 Index was selected for the US equity market index for two reasons. First, it represents the top 3000 stocks by market capitalization (FTSE Russell 2016). This represents a significant proportion of the investable universe of US stocks. Second, for consistency, in the factor-exposure studies we employ the Russell indices to create the factor proxies.

5.4.3 UK asset class reference portfolio

To test the mean–variance spanning properties of the PFI portfolio, we build a UK asset class reference portfolio consisting of:

- Fixed interest, represented by the Bank of America/ML UK Gilts Index;
- Real estate, proxied by the DataStream UK Real Estate Index;
- Hedge funds, represented by the UK DataStream Hedge Funds Index;
- Commodities, as proxied by the S&P Goldman Sachs Commodity Index;
- UK equities represented by the FTSE100; and
- World equities proxied by the FTSE World ex-UK.

The returns, standard deviation, and Sharpe ratios for the UK reference asset classes are presented in Panel C of Table 13. For the price returns, the fixed-interest proxy exhibits the highest returns, and the proxy employed for UK stock returns exhibits the lowest. Fixed interest again exhibits the lowest standard deviation, whereas commodities exhibit the highest. As a result, the fixed-interest proxy has the highest Sharpe ratio, while UK stocks have the lowest.

When total returns are considered, real estate now exhibits the highest return and commodities the lowest. For standard deviation, fixed interest again exhibits the lowest and commodities the highest. The highest Sharpe ratio is again fixed interest with commodities exhibiting the lowest.

5.4.4 Global factor-based reference portfolio

Consistent with prior research, the factors in this study are constructed from stock and bond market indices. We follow Bender et al. (2010), Ilmanen and Kizer (2012), and Bird et al. (2013) to build market, size, value, term, and default factors.

- The market factor is the excess return of the MSCI US and MSCI Europe indices.
- The size factor is calculated by taking the difference between the simple average of MSCI Small Value and Growth indices and the simple average of MSCI Large Value and Growth indices.
- The value factor is constructed by obtaining the difference between simple average of MSCI Small-, Mid-, and Large-Value indices and simple average of MSCI Small-, Mid-, and Large-Growth indices.
- The term factor is estimated by taking the difference between the returns of the US government 10-Year Index and S&P US Treasury Bill 0–3 Index.
- Finally, the default factor is estimated by the change in the Moody's Seasoned Baa Corporate Bond Yield relative to the yield on 10-Year Treasury constant maturity.

The price and total return summary statistics for the factor portfolios are described in Table 14. The average price returns for both the US and Europe market factors are negative and with a higher standard deviation than the size and value factors. For the total returns, the Europe market factor is still negative, along with the default factor. The US market factor is positive but smaller than all other factors apart from the default and Europe market factors. The size factor exhibits the lowest standard deviation; the default factor exhibits the highest. As a result, the size factor has the highest Sharpe ratio and the default factor the lowest.

5.4.5 US factor-based reference portfolio

US factors are computed using the now canonical formulas reported in Faff (2001):

- $\text{SMB} = \frac{(\text{Russell 2000 Value + Russell 2000 Growth})}{2} - \frac{(\text{Russell 1000 Value+Russell 1000 Growth})}{2}$;
- $\text{HML} = \frac{(\text{Russell 1000 Value + Russell 2000 Value})}{2} - \frac{(\text{Russell 1000 Growth+Russell 2000 Growth})}{2}$;
- Term = Barclays US Treasury 10–20 Years Index–Barclays US Treasury Bills 1–3 Months Index;
- Default = Barclays US Corporate: AAA Long Index-Barclays US Treasury Long Index; and
- Market = Russell 3000 Index–US 1-month Treasury Bill return

Panel B of Table 14 displays the descriptive statistics for the US factors. Both the term and default factors' average price returns are negative, with the value factor exhibiting the highest average return. The price returns of the US market factor exhibit the highest standard deviation and the default factor the lowest.

For the total returns, the term factor has the highest average return, whereas the size factor has the lowest. As with the price returns, the default factor exhibits the lowest standard deviation; the market exhibits the highest.

In the next section, we present the results of the mean–variance spanning tests presented in Sect. 4 using the multiple datasets described above.

6 Results

We first present, in Sect. 6.1, the results of the mean–variance spanning tests conducted using the asset classes as the reference assets. Next, we use the factor proxies defined above as the reference portfolio. We report the Huberman and Kandel (1987) regression results for Eq. (1) and the corresponding Kan and Zhou (2012) two-stage, step-down tests.

6.1 Asset class mean–variance spanning test results

Here, we discuss test results for infrastructure defined as listed infrastructure companies (Sect. 6.1.1), global listed infrastructure indices (Sect. 6.1.2), US-based listed infrastructure indices (Sect. 6.1.3), and the PFI portfolio (Sect. 6.1.4).

6.1.1 Listed infrastructure companies

The results of the mean–variance spanning test for the naïve infrastructure portfolios are reported in Table 5. For the price returns of the nine portfolios constructed, Table 5 shows that the reference investment-opportunity set is improved by four of these portfolios. These are the 75% revenue cutoff transport portfolio and the telecommunication portfolios. However, when total returns are examined, only the 50% telecoms and the 75% transport infrastructure portfolio are found to reject the Huberman and Kandel (1987) null hypothesis of spanning at conventional significance levels. *No other portfolio improves on the mean–variance frontier created by the reference asset classes.*

Table 5 Results for the mean–variance spanning tests for naïve infrastructure portfolios with asset class-built reference portfolio

	50% Rev. Tel.	50% Rev. Trans.	50% Rev. Util.	75% Rev. Tel.	75% Rev. Trans.	75% Rev. Util.	90% Rev. Tel.	90% Rev. Trans.	90% Rev. Util.
Price returns									
Panel A: 01/00–12/14									
H & K	5.9995	1.4399	1.4685	4.4346	9.4460	1.1629	4.7566	0.1140	0.9837
p value	0.0030	0.2398	0.2331	0.0132	0.0001	0.3150	0.0098	0.8923	0.3760
Stepdown1	11.4124	0.6673	0.8408	8.1672	0.0605	0.3787	8.7251	0.1894	0.6453
p value	0.0009	0.4151	0.3604	0.0048	0.8060	0.5391	0.0036	0.6639	0.4229
Stepdown2	0.5534	2.2168	2.0981	0.6742	18.9336	1.9541	0.7545	0.0388	1.3248
p value	0.4579	0.1383	0.1493	0.4127	0.0000	0.1639	0.3862	0.8440	0.2513
Panel B: 01/00–12/08									
H & K	2.7789	1.0327	0.3148	1.5847	5.1403	0.5791	1.3413	0.5641	0.2671
p value	0.0669	0.3598	0.7307	0.2101	0.0075	0.5622	0.2662	0.5707	0.7661
Stepdown1	4.7052	0.5691	0.1516	2.6911	0.1091	0.3918	2.4454	0.0061	0.1606
p value	0.0324	0.4524	0.6979	0.1041	0.7419	0.5328	0.1210	0.9379	0.6894
Stepdown2	0.8225	1.5027	0.4820	0.4704	10.2620	0.7712	0.2339	1.1333	0.3768
p value	0.3666	0.2231	0.4891	0.4944	0.0018	0.3819	0.6297	0.2896	0.5407
Panel C: 01/09–12/14									
H & K	1.9650	0.1961	9.4648	2.5562	1.5677	7.2259	2.4927	1.8230	5.5060
p value	0.1484	0.8224	0.0002	0.0854	0.2163	0.0015	0.0906	0.1697	0.0062
Stepdown1	2.1676	0.3829	13.5665	2.7828	0.2542	11.5787	4.4232	0.0683	8.9767
p value	0.1458	0.5382	0.0005	0.1001	0.6159	0.0011	0.0393	0.7946	0.0039
Stepdown2	1.7319	0.0094	4.5052	2.2683	2.9142	2.4763	0.5344	3.6290	1.8158
p value	0.1927	0.9229	0.0375	0.1368	0.0925	0.1204	0.4673	0.0611	0.1824

Table 5 continued

	50% Rev. Tel.	50% Rev. Trans.	50% Rev. Util.	75% Rev. Tel.	75% Rev. Trans.	75% Rev. Util.	90% Rev. Tel.	90% Rev. Trans.	90% Rev. Util.
Total returns									
Panel D: 01/00–12/14									
H & K	4.1227	1.0944	0.7730	2.8372	9.9398	0.7009	2.8997	0.8547	0.3654
p value	0.0178	0.3371	0.4632	0.0613	0.0001	0.4975	0.0577	0.4272	0.6945
Stepdown1	7.8185	0.0279	0.0069	5.0241	0.3657	0.1568	4.8271	1.6359	0.0590
p value	0.0058	0.8677	0.9340	0.0263	0.5462	0.6926	0.0293	0.2026	0.8083
Stepdown2	0.4109	2.1730	1.5479	0.6356	19.5852	1.2512	0.9514	0.0732	0.6754
p value	0.5223	0.1423	0.2151	0.4264	0.0000	0.2649	0.3307	0.7870	0.4123
Panel E: 01/00–12/08									
H & K	2.3508	0.6169	0.6647	1.2237	4.7298	1.1515	0.8439	1.1320	0.7195
p value	0.1005	0.5416	0.5167	0.2985	0.0109	0.3203	0.4330	0.3265	0.4895
Stepdown1	3.7987	0.2847	0.8781	1.9978	0.0220	1.6295	1.6151	0.2724	1.1584
p value	0.0541	0.5948	0.3510	0.1606	0.8824	0.2047	0.2067	0.6029	0.2844
Stepdown2	0.8786	0.9560	0.4519	0.4452	9.5298	0.6693	0.0724	2.0062	0.2803
p value	0.3508	0.3305	0.5030	0.5061	0.0026	0.4152	0.7884	0.1597	0.5977
Panel F: 01/09–12/14									
H & K	0.4033	0.0241	4.7507	0.5286	3.0172	3.9925	0.2831	3.1475	2.9174
p value	0.6698	0.9762	0.0119	0.5919	0.0558	0.0232	0.7544	0.0496	0.0612
Stepdown1	0.0182	0.0000	6.7268	0.0004	1.7058	6.8025	0.3114	0.4509	5.1591
p value	0.8932	0.9982	0.0117	0.9842	0.1961	0.0113	0.5787	0.5043	0.0264
Stepdown2	0.8004	0.0490	2.5531	1.0731	4.2828	1.0868	0.2574	5.8931	0.6357
p value	0.3742	0.8255	0.1149	0.3040	0.0424	0.3010	0.6136	0.0179	0.4281

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index reports for the period January 2000 to December 2008 and for the period January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

Applying the Kan and Zhou (2012) methodology, the results in Table 5 show that none of the infrastructure portfolios improve the mean–variance frontier from that created by the reference investments. Indeed, the listed infrastructure portfolios neither improve the tangent portfolio nor produce a lower minimum variance portfolio. This finding is consistent when either price or total returns are used.

When the subperiods are considered, both before and after the GFC, the conclusion that the naïve infrastructure approach fails to identify any diversification benefits is supported.

Panels B and D of Table 5 present the results for the mean–variance spanning tests for the period January 2000 to December 2008. The Huberman and Kandel (1987) test's null hypothesis is rejected in two cases: the price and total returns of the 75% transport portfolio. However, the Kan and Zhou (2012) test fails to reject the null hypothesis.

From January 2009 to December 2014 (Panels C and F of Table 5), only one portfolio improves the efficient frontier, the price returns of the 50% utilities portfolio. Here, the Huberman and Kandel (1987) portfolio's null hypothesis is rejected at the 5% significance level and both steps of the Kan and Zhou (2012) test reject the null hypothesis that the portfolio's risk and returns are already spanned by the reference assets.

However, just one portfolio out of the nine tested was statistically significant, which fails to provide systematic evidence for the existence of a listed infrastructure asset class. Figure 1 illustrates the findings in Table 5 by showing the mean–variance frontier with and without the addition of the naïve 90% utilities portfolio for the period January 2009 to December 2014. The results in Table 5 confirm that this portfolio does not improve the investment-opportunity set despite the efficient frontier shifting to the left. This is because the global minimum variance is not statistically different as a result of adding infrastructure to the asset class mix.

Next, we discuss our results using industry-provided infrastructure indices as proxies for the infrastructure asset class, testing whether there are diversification benefits from a global asset class-based reference portfolio.

6.1.2 Global infrastructure indices

Table 6 presents our results for the global infrastructure price and total return indices described in Sect. 5. Here, using price returns for the full sample period (Panel A, Table 6), the Huberman and Kandel (1987) test demonstrates a statistically significant improvement in the efficient frontier in six of the eight infrastructure indices examined. However, the more restrictive Kan and Zhou (2012) test finds that only two of the eight global infrastructure indices improve the efficient frontier: the Dow Jones Brookfield Global Infrastructure Index and the UBS Infrastructure and Utilities Index. Indices found to improve the efficient frontier by the Huberman and Kandel (1987) test are here found to improve the tangency portfolio or the minimum variance portfolio but not both. As a result, it cannot be assumed that these indices improve the efficient frontier.

Using total returns (Panel D, Table 6), again six of the eight global indices reject the null of the Huberman and Kandel (1987) test. The FTSE Core Index fails to span when

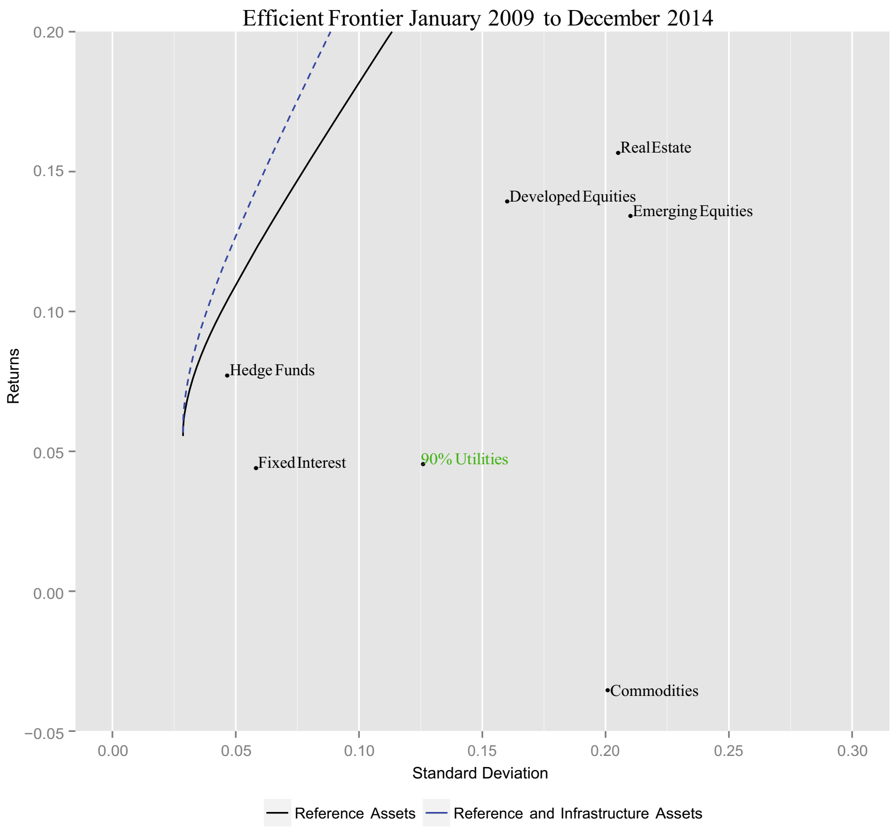

Fig. 1 Mean–variance frontier of 90% revenue threshold utilities and asset class reference portfolio

either the price or total returns are employed, whereas the MSCI World Infrastructure is not spanned by the reference asset classes using price returns, but is spanned when considering total returns. The reverse is true for the UBS 50-50.

Using the Kan and Zhou (2012) test, four of the eight global infrastructure indices are found to improve the efficient frontier, but Table 6 shows that most indices found by the Huberman and Kandel (1987) test to improve the efficient frontier only improved the minimum variance portfolio but not the tangency portfolio. As a result, it is not possible to conclude that these listed infrastructure indices are not spanned by existing asset classes.

In the subperiod analysis, for price returns pre-GFC (Panels B and E of Table 6), the Huberman and Kandel (1987) test finds that four of the eight global listed infrastructure indices improve the efficient frontier. However, the Kan and Zhou (2012) test finds that these indices improve only the minimum variance portfolio and not the tangency portfolio.

When total returns are considered for the same period, the Huberman and Kandel (1987) test finds that all the listed infrastructure indices improve the efficient frontier. The results of the Kan and Zhou (2012) test, however, indicate that although the global

Table 6 Results for global listed infrastructure indices with asset class-built reference portfolio

	DJ Brook-field	S&P Global Infra.	FTSE Macq.	FTSE Core	MSCI World Infra.	MSCI ACWI	UBS	UBS50-50
Price returns								
Panel A: 01/00–12/14								
H & K	6.2379	10.4252	3.1041	1.1562	3.1364	16.4068	7.8483	3.0324
p value	0.0026	0.0001	0.0475	0.3188	0.0459	0.0000	0.0005	0.0508
Stepdown1	4.2128	0.0823	0.0125	1.2090	3.9114	2.6229	4.0417	1.5627
p value	0.0420	0.7746	0.9110	0.2742	0.0495	0.1072	0.0459	0.2130
Stepdown2	8.0749	20.8950	6.2323	1.1011	2.3224	29.9118	11.4546	4.4876
p value	0.0052	0.0000	0.0135	0.2965	0.1293	0.0000	0.0009	0.0356
Panel B: 01/00–12/08								
H & K	3.0164	8.6243	4.4154	2.2605	2.9377	10.5604	5.5502	2.5240
p value	0.0560	0.0004	0.0147	0.1230	0.0576	0.0001	0.0052	0.0852
Stepdown1	1.8074	0.9489	1.0874	2.4140	0.7302	2.0287	3.2296	3.0950
p value	0.1836	0.3331	0.2997	0.1315	0.3948	0.1575	0.0753	0.0816
Stepdown2	4.1735	16.3104	7.7363	2.0090	5.1589	18.8996	7.7009	1.9133
p value	0.0451	0.0001	0.0065	0.1670	0.0252	0.0000	0.0066	0.1696
Panel C: 01/09–12/14								
H & K	3.7596	1.1947	1.2867	0.2095	0.8007	3.0735	2.1329	1.3365
p value	0.0285	0.3093	0.2831	0.8115	0.4534	0.0530	0.1267	0.2699
Stepdown1	3.7266	0.8322	2.5164	0.4114	1.5921	0.4940	0.2978	0.5041
p value	0.0579	0.3650	0.1175	0.5235	0.2115	0.4847	0.5872	0.4802
Stepdown2	3.6421	1.5613	0.0557	0.0078	0.0092	5.6966	4.0106	2.1854
p value	0.0607	0.2159	0.8141	0.9300	0.9240	0.0199	0.0493	0.1441
Total returns								
Panel D: 01/00–12/14								
H & K	8.7138	13.8824	4.5856	2.8989	2.0253	17.6365	8.9542	4.8912
p value	0.0003	0.0000	0.0115	0.0597	0.1351	0.0000	0.0002	0.0086
Stepdown1	7.9255	2.9554	0.8898	3.9974	0.8027	8.3858	7.9378	4.3504
p value	0.0056	0.0877	0.3469	0.0483	0.3715	0.0043	0.0054	0.0385
Stepdown2	9.0480	24.4921	8.2868	1.7490	3.2516	25.7925	9.5882	5.3294
p value	0.0031	0.0000	0.0045	0.1890	0.0731	0.0000	0.0023	0.0221
Panel E: 01/00–12/08								
H & K	4.1011	11.4168	6.0174	2.9031	2.9696	11.4718	6.2768	3.8680
p value	0.0211	0.0000	0.0035	0.0715	0.0559	0.0000	0.0027	0.0241
Stepdown1	3.1992	4.0673	2.9175	3.3744	0.0282	4.7157	5.6679	5.4413
p value	0.0784	0.0472	0.0909	0.0769	0.8669	0.0323	0.0192	0.0217
Stepdown2	4.8393	18.0563	8.9370	2.2478	5.9684	17.5811	6.5815	2.1979
p value	0.0314	0.0001	0.0036	0.1446	0.0163	0.0001	0.0118	0.1413

Table 6 continued

	DJ Brook-field	S&P Global Infra.	FTSE Macq.	FTSE Core	MSCI World Infra.	MSCI ACWI	UBS	UBS50-50
Panel F: 01/09–12/14								
H & K	5.9270	1.3337	0.2773	1.1776	0.1752	3.7857	2.5662	1.2466
p value	0.0043	0.2706	0.7587	0.3145	0.8397	0.0278	0.0846	0.2943
Stepdown1	7.1569	0.0031	0.5185	2.1403	0.0143	3.5961	0.9395	0.0490
p value	0.0094	0.9556	0.4741	0.1483	0.9051	0.0624	0.3360	0.8255
Stepdown2	4.2964	2.7051	0.0364	0.2113	0.3411	3.8247	4.1967	2.4799
p value	0.0421	0.1048	0.8493	0.6473	0.5612	0.0547	0.0445	0.1201

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index returns for the periods January 2000 to December 2008 and January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

indices improved on the tangency portfolio, in the period of analysis, not all reduced the minimum variance portfolio. As a result, in the pre-GFC sample, only FTSE Core, MSCI World Infrastructure, and the MSCI ACWI Capped infrastructure indices can be said to improve the efficient frontier, as they both improve the tangency portfolio and reduce the minimum variance portfolio.

Post-GFC (Panels C and F of Table 6), the pre-GFC results are invalidated. Using price returns, only one of the eight indices examined is found to improve the efficient frontier under both the Huberman and Kandel (1987) and Kan and Zhou (2012) tests: the Dow Jones Brookfield index. Using total returns again, only one index is found to improve the efficient frontier under both the Huberman and Kandel (1987) and Kan and Zhou (2012) tests: the MSCI ACWI Capped Index.

Hence, the pre-GFC results are not persistent post-GFC. These results argue against the existence of a well-defined and persistent listed infrastructure asset class.

6.1.3 US infrastructure indices

The results for US listed infrastructure indices are presented in Table 7.

The Huberman and Kandel (1987) results in Table 7 indicate that for the full period (Panels A and D) both the price returns and total returns of the Alerian MLP Infrastructure Index improve the efficient frontier. None of the other infrastructure indices reject the null hypothesis that the existing asset class investments span the risk and returns provided by the listed infrastructure indices.

When the Kan and Zhou (2012) test is employed, the conclusion that the Alerian MLP Infrastructure Index improves the investment-opportunity set is reversed for both the price and total return indices. Although the Kan and Zhou (2012) test finds that the tangency portfolio has improved, it does not reject the null hypothesis that the global minimum variance has improved. As a result, it is not possible to conclude that the inclusion of the Alerian MLP Infrastructure Index improves the investment

Table 7 Results for the US listed infrastructure indices with asset class-built reference portfolio

	Alerian MLP	FTSE Macquarie USA	MSCI USA Infrastructure	MSCI USA Infrastructure Capped
Price returns				
Panel A: January 2000 to December 2014				
H & K	3.5537	0.9730	0.4046	1.7772
p value	0.0308	0.3821	0.6679	0.1722
Stepdown1	6.8957	0.0604	0.0512	0.3592
p value	0.0094	0.8064	0.8212	0.5498
Stepdown2	0.2048	1.9064	0.7622	3.2072
p value	0.6515	0.1709	0.3839	0.0751
Panel B: January 2000 to December 2008				
H & K	1.9041	0.3161	0.4258	2.2540
p value	0.1544	0.7349	0.6545	0.1104
Stepdown1	3.7423	0.5859	0.0962	0.1576
p value	0.0559	0.4588	0.7570	0.6922
Stepdown2	0.0640	0.0477	0.7623	4.3878
p value	0.8008	0.8305	0.3847	0.0388
Panel C: January 2009 to December 2014				
H & K	0.8072	0.1190	0.0891	0.0867
p value	0.4507	0.8880	0.9148	0.9171
Stepdown1	1.6137	0.0577	0.1382	0.0350
p value	0.2086	0.8109	0.7114	0.8523
Stepdown2	0.0007	0.1830	0.0407	0.1405
p value	0.9797	0.6702	0.8408	0.7090
Total returns				
Panel D: January 2000 to December 2014				
H & K	6.0024	1.1463	0.6895	1.9286
p value	0.0030	0.3227	0.5032	0.1485
Stepdown1	11.6155	0.0121	0.0246	0.9511
p value	0.0008	0.9128	0.8756	0.3308
Stepdown2	0.3666	2.3070	1.3622	2.9069
p value	0.5456	0.1325	0.2448	0.0900
Panel E: January 2000 to December 2008				
H & K	3.8572	0.2963	0.5864	2.3219
p value	0.0244	0.7488	0.5583	0.1035
Stepdown1	7.4502	0.4998	0.0063	0.2440
p value	0.0075	0.4931	0.9368	0.6225
Stepdown2	0.2480	0.0966	1.1783	4.4336
p value	0.6196	0.7609	0.2803	0.0378

Table 7 continued

	Alerian MLP	FTSE Macquarie USA	MSCI USA Infrastructure	MSCI USA Infrastructure Capped
Panel F: January 2009 to December 2014				
H & K	0.7444	0.1307	0.4085	0.3702
p value	0.4791	0.8777	0.6664	0.6921
Stepdown1	1.3711	0.0963	0.7868	0.3305
p value	0.2460	0.7574	0.3784	0.5674
Stepdown2	0.1171	0.1674	0.0304	0.4143
p value	0.7333	0.6838	0.8622	0.5221

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index returns for the periods January 2000 to December 2008 and January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

universe. As the other infrastructure indices do not reject the null hypothesis, the same conclusions apply to them.

When pre- and post-GFC subsamples are considered (Panels B, C, E, and F of Table 7), the conclusion that listed infrastructure assets do not improve the investment universe continues to be supported. For the first subperiod, only the total returns of the Alerian MLP Infrastructure Index rejects the null hypothesis of the Huberman and Kandel (1987) test, as illustrated by Fig. 2.

When the Kan and Zhou (2012) test is employed, none of the indices can reject both steps of the test. It is not possible to conclude that the inclusion of infrastructure indices improves the mean variance of traditional asset classes in this sample period. Using the second subsample period, none of the indices, either using total or price returns, are found to reject the null hypothesis, leading to the conclusion that none of the indices improve an investor's diversification opportunities.

6.1.4 PFI portfolio

Finally, we report, in Table 8, the ability of our PFI portfolio to improve the mean–variance efficiency of a diversified investor in the UK. For the complete sample, the price return series does not provide diversification benefits. However, total return results are found to improve on the reference efficient frontier when investing over the entire period, as Fig. 3 illustrates. The total return PFI portfolio passes both the Huberman and Kandel (1987) and the Kan and Zhou (2012) tests for the full sample period.

The subperiod analysis shows that the diversification benefits appear only in the period following the GFC. Prior to the GFC, neither price nor total returns of the PFI portfolios improve the efficient frontier. Total returns, for example, produce diversification benefits according to the Huberman and Kandel (1987) test, but the Kan and Zhou (2012) test finds that these benefits are simply due to a change in the global minimum variance portfolio. Without a corresponding increase in the tangency portfolio,

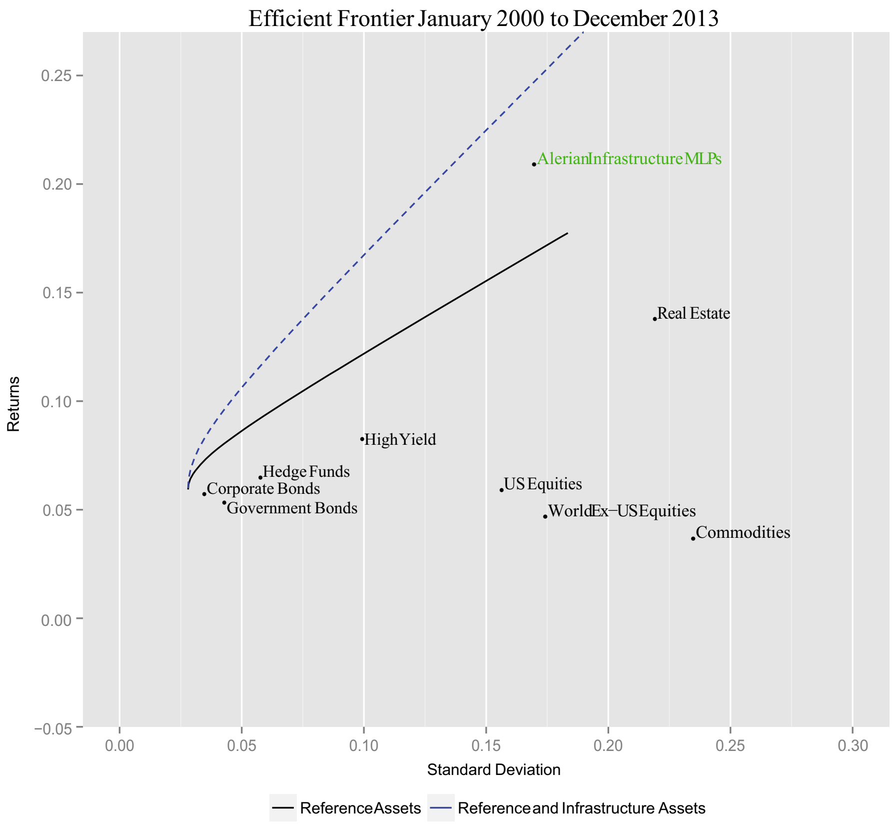

Fig. 2 Mean–variance frontier of Alerian MLP Index asset class proxies

Table 8 Results for the mean–variance spanning test for the PFI stocks with asset class-built reference portfolio

	Price returns			Total returns		
	Full sample	Pre-GFC	Post-GFC	Full sample	Pre-GFC	Post-GFC
H & K	0.4211	0.4173	7.9863	5.7016	1.3958	7.6910
p value	0.6575	0.6630	0.0008	0.0045	0.2649	0.0010
Stepdown1	0.0000	0.6413	1.1721	5.4260	1.4184	9.1745
p value	0.9997	0.4302	0.2830	0.0219	0.2440	0.0035
Stepdown2	0.8508	0.1959	14.7621	5.7239	1.3529	5.5234
p value	0.3586	0.6615	0.0003	0.0186	0.2546	0.0218

Full sample refers to the time period April 2006 to December 2014. Pre-GFC refers to the time period April 2006 to December 2008, and post-GFC refers to the time period January 2009 to December 2014

it is not possible to conclude that the efficient frontier has been improved. Still, these results may be considered inconclusive, as PFI portfolio returns have a short history, beginning only in 2006.

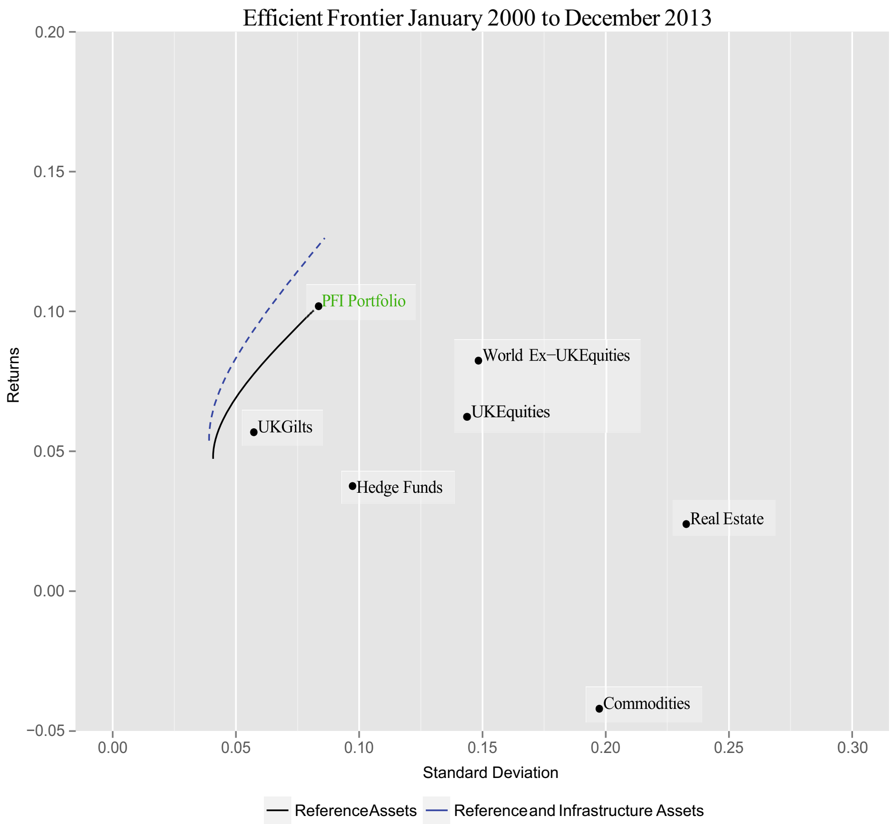

Fig. 3 Mean–variance frontier of total returns PFI portfolio and reference portfolio

After the GFC, however, the price returns of the PFI portfolio pass the Huberman and Kandel (1987) test. The Kan and Zhou (2012) test finds that this is simply due to the improvement in the minimum variance portfolio but not the tangency portfolio. However, the total return PFI portfolio is found by both the Huberman and Kandel (1987) and Kan and Zhou (2012) tests to exhibit diversification benefits.

Hence, the impact of the PFI portfolio appears to be one of the most persistent of the various infrastructure portfolios that were tested on a total return basis. It improves diversification for the entire investment period and, crucially, post-GFC, when all but one of the other infrastructure indices fail to pass the post-GFC test of persistence.

6.2 Factor-based mean–variance spanning test results

Next, we examine how the various listed infrastructure definitions proposed above fare against a factor-based reference portfolio, that is, whether investing in listed infrastructure creates an exposure to a combination of factors not otherwise available to investors already allocating to the well-known factors described in Sect. 5.4.

As above, we first present our results for listed infrastructure companies (Sect. 6.2.1), followed by global listed infrastructure (Sect. 6.2.2), and US infrastructure indices (Sect. 6.2.3). Unfortunately, at this stage, we cannot build a reference factor portfolio for the UK due to lack of sufficient data.

6.2.1 Listed infrastructure companies

Table 9 presents our results for the infrastructure portfolios using the naïve infrastructure definition proposed in Sect. 5. Using the full sample (Panels A and D of Table 9), the Huberman and Kandel (1987) test rejects the null hypothesis that the efficient frontier is not improved in five of the nine price return indices and six of the nine total return indices. Applying the Kan and Zhou (2012) test, however, there is no evidence that infrastructure, thus defined, provides diversification benefits. Indices that qualified under the Huberman and Kandel (1987) test all fail to reject the null hypothesis for both steps of the Kan and Zhou (2012) test. Consistent with the findings for the asset class reference portfolio, the addition of listed infrastructure companies to a factor-based allocation does not improve the mean–variance frontier.

Pre- and post-GFC results are consistent with the full sample. In the period January 2000 to December 2008 (Panels B and E of Table 9), eight of the nine price return indices are found to improve the efficient frontier according to the Huberman and Kandel (1987) test. When the Kan and Zhou (2012) test is applied, however, this positive result is overturned, with none of the indices examined passing the two-stage test. When total returns are employed, the results are the same.

For the period January 2009 to December 2014 (Panels C and F of Table 9), results mirror the pre-GFC sample. For the price return indices, the Huberman and Kandel (1987) test finds that the mean–variance frontier is improved in six of the naïve infrastructure portfolios. However, the Kan and Zhou (2012) test results do not support these findings, and none of the portfolios qualify. The total returns for naïve infrastructure portfolios lead to the same conclusions.

6.2.2 Global infrastructure indices

The results for the spanning tests for global listed infrastructure indices are presented in Table 10. The results will be by now familiar.

Using price returns for the full sample (Panel A of Table 10), six of the eight indices examined reject the null of the Huberman and Kandel (1987) test at the 5% level, but the Kan and Zhou (2012) test indicates that only two of the eight indices improve both the tangency portfolio as well as the global minimum variance portfolio: Only the Dow Jones Brookfield and FTSE Core Infrastructure Index can be said to improve the reference efficient frontier.

For the period January 2000 to December 2008 (Panel B of Table 10), only four of the eight indices are found to reject the null of the Huberman and Kandel (1987) test at the 5% level, but none of these pass the Kan and Zhou (2012) test. Between January 2009 and December 2014 (Panel C of Table 10), only two of the eight portfolios are found to reject the null of the Huberman and Kandel (1987) test at the 5% level. Of

Table 9 Results for the factor asset class and the naïve infrastructure portfolios with factor-based reference portfolios

	50% Rev. Tel.	50% Rev. Transp.	50% Rev. Util.	75% Rev. Tel.	75% Rev. Transp.	75% Rev. Util.	90% Rev. Tel.	90% Rev. Transp.	90% Rev. Util.
Price returns									
Panel A: 01/00–12/14									
H & K	47.8309	2.6335	1.8876	41.8602	3.4973	1.3880	37.0500	3.3250	0.9726
p value	0.0000	0.0747	0.1545	0.0000	0.0324	0.2523	0.0000	0.0383	0.3801
Stepdown1	0.0268	1.0904	0.0796	0.0072	6.0392	0.1121	0.0293	1.8583	0.0551
p value	0.8702	0.2978	0.7781	0.9323	0.0150	0.7382	0.8644	0.1746	0.8147
Stepdown2	96.1669	4.1744	3.7149	84.1880	0.9289	2.6775	74.4815	4.7685	1.9003
p value	0.0000	0.0425	0.0555	0.0000	0.3365	0.1036	0.0000	0.0303	0.1698
Panel B: 01/00–12/08									
H & K	19.1594	3.4947	4.5904	19.7341	1.5564	3.1284	14.6323	6.6493	2.6374
p value	0.0000	0.0340	0.0123	0.0000	0.2159	0.0480	0.0000	0.0019	0.0764
Stepdown1	1.3241	0.1873	1.8145	1.1258	1.5529	1.4435	0.9763	0.3731	0.9605
p value	0.2526	0.6661	0.1809	0.2912	0.2156	0.2324	0.3254	0.5427	0.3294
Stepdown2	36.8786	6.8562	7.3084	38.2956	1.5515	4.7927	28.2949	13.0045	4.3160
p value	0.0000	0.0102	0.0080	0.0000	0.2157	0.0308	0.0000	0.0005	0.0402
Panel C: 01/09–12/14									
H & K	8.5824	2.0454	4.8455	5.5339	3.2293	0.8911	6.7757	3.7488	0.7437
p value	0.0005	0.1373	0.0108	0.0060	0.0458	0.4150	0.0021	0.0286	0.4792
Stepdown1	0.0032	0.2274	5.7212	0.3092	3.3858	1.7022	0.0340	1.2738	1.1817
p value	0.9548	0.6350	0.0196	0.5800	0.0702	0.1965	0.8542	0.2631	0.2809
Stepdown2	17.4170	3.9078	3.7121	10.8691	2.9687	0.0791	13.7121	6.1988	0.3049
p value	0.0001	0.0521	0.0582	0.0016	0.0894	0.7794	0.0004	0.0152	0.5826

Table 9 continued

	50% Rev. Tel.	50% Rev. Transp.	50% Rev. Util.	75% Rev. Tel.	75% Rev. Transp.	75% Rev. Util.	90% Rev. Tel.	90% Rev. Transp.	90% Rev. Util.
Total returns									
Panel D: 01/00–12/14									
H & K	49.0714	4.1465	2.4766	44.8485	5.3390	2.0835	38.3526	4.7065	1.6385
p value	0.0000	0.0174	0.0870	0.0000	0.0056	0.1276	0.0000	0.0102	0.1972
Stepdown1	0.6454	1.4520	0.3163	0.6925	9.5743	0.8237	0.5196	4.0237	0.6781
p value	0.4228	0.2298	0.5745	0.4064	0.0023	0.3654	0.4720	0.0464	0.4114
Stepdown2	97.6941	6.8235	4.6550	89.1603	1.0524	3.3467	76.3942	5.2982	2.6038
p value	0.0000	0.0098	0.0323	0.0000	0.3064	0.0690	0.0000	0.0225	0.1084
Panel E: 01/00–12/08									
H & K	23.2175	4.4858	5.2056	23.3121	2.0385	3.7743	18.4482	6.8887	3.3058
p value	0.0000	0.0136	0.0070	0.0000	0.1355	0.0262	0.0000	0.0016	0.0406
Stepdown1	2.8219	0.1478	2.0863	2.2061	2.5522	2.3533	2.1082	0.9129	1.7675
p value	0.0960	0.7014	0.1517	0.1405	0.1132	0.1281	0.1496	0.3416	0.1867
Stepdown2	42.8549	8.8974	8.2379	43.9038	1.5023	5.1278	34.4179	12.8754	4.8083
p value	0.0000	0.0036	0.0050	0.0000	0.2231	0.0256	0.0000	0.0005	0.0306
Panel F: 01/09–12/14									
H & K	5.2249	1.6536	3.3435	3.8623	4.5354	0.4192	3.7247	5.2298	0.3791
p value	0.0078	0.1991	0.0413	0.0259	0.0142	0.6593	0.0293	0.0078	0.6859
Stepdown1	0.6878	0.9210	3.2420	0.4323	5.7151	0.7647	0.3616	3.4145	0.4485
p value	0.4099	0.3407	0.0763	0.5131	0.0196	0.3850	0.5496	0.0690	0.5053
Stepdown2	9.8071	2.3890	3.3352	7.3537	3.1381	0.0739	7.1550	6.8036	0.3123
p value	0.0026	0.1268	0.0722	0.0085	0.0810	0.7866	0.0094	0.0112	0.5781

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index returns for the periods January 2000 to December 2008 and January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

Table 10 Results for the global listed infrastructure indices with factor-based reference portfolios

	DJ Brook-field	S&P Global Infra.	FTSE Macq.	FTSE Core	MSCI World Infra.	MSCI ACWI	UBS	UBS50-50
Price returns								
Panel A: 01/00–12/14								
H & K	6.2379	10.4252	3.1041	1.1562	3.1364	16.4068	7.8483	3.0324
p value	0.0026	0.0001	0.0475	0.3188	0.0459	0.0000	0.0005	0.0508
Stepdown1	4.2128	0.0823	0.0125	1.2090	3.9114	2.6229	4.0417	1.5627
p value	0.0420	0.7746	0.9110	0.2742	0.0495	0.1072	0.0459	0.2130
Stepdown2	8.0749	20.8950	6.2323	1.1011	2.3224	29.9118	11.4546	4.4876
p value	0.0052	0.0000	0.0135	0.2965	0.1293	0.0000	0.0009	0.0356
Panel B: 01/00–12/08								
H & K	3.0164	8.6243	4.4154	2.2605	2.9377	10.5604	5.5502	2.5240
p value	0.0560	0.0004	0.0147	0.1230	0.0576	0.0001	0.0052	0.0852
Stepdown1	1.8074	0.9489	1.0874	2.4140	0.7302	2.0287	3.2296	3.0950
p value	0.1836	0.3331	0.2997	0.1315	0.3948	0.1575	0.0753	0.0816
Stepdown2	4.1735	16.3104	7.7363	2.0090	5.1589	18.8996	7.7009	1.9133
p value	0.0451	0.0001	0.0065	0.1670	0.0252	0.0000	0.0066	0.1696
Panel C: 01/09–12/14								
H & K	6.5136	0.6060	0.0344	1.8708	2.8372	4.4366	2.1674	1.7735
p value	0.0026	0.5485	0.9662	0.1620	0.0657	0.0155	0.1224	0.1776
Stepdown1	8.3745	0.9974	0.0595	2.3981	0.5068	2.1816	4.3189	3.4760
p value	0.0051	0.3215	0.8081	0.1262	0.4790	0.1444	0.0415	0.0666
Stepdown2	4.1975	0.2146	0.0096	1.3164	5.2053	6.5773	0.0151	0.0684
p value	0.0443	0.6447	0.9224	0.2553	0.0257	0.0125	0.9025	0.7944
Total returns								
Panel D: 01/00–12/14								
H & K	9.3519	12.1028	5.7400	5.1611	12.4659	9.6688	3.9037	10.4645
p value	0.0002	0.0000	0.0039	0.0073	0.0000	0.0001	0.0220	0.0001
Stepdown1	18.0756	15.6201	6.1167	7.4542	1.8860	9.5355	7.7860	10.9591
p value	0.0000	0.0001	0.0144	0.0075	0.1714	0.0023	0.0059	0.0011
Stepdown2	0.5590	7.8277	5.2047	2.6972	22.9290	9.3438	0.0207	9.4302
p value	0.4559	0.0058	0.0238	0.1036	0.0000	0.0026	0.8857	0.0025
Panel E: 01/00–12/09								
H & K	7.0486	8.3514	4.5794	9.2948	21.4088	7.4560	4.0881	8.3279
p value	0.0017	0.0005	0.0126	0.0007	0.0000	0.0010	0.0196	0.0004
Stepdown1	13.2588	16.6604	8.7027	9.1231	4.4843	9.8566	8.0081	14.1227
p value	0.0005	0.0001	0.0040	0.0051	0.0366	0.0022	0.0056	0.0003
Stepdown2	0.7087	0.0354	0.4225	7.5010	37.0790	4.6552	0.1573	2.2468
p value	0.4029	0.8512	0.5172	0.0101	0.0000	0.0333	0.6925	0.1370

Table 10 continued

	DJ Brook-field	S&P Global Infra.	FTSE Macq.	FTSE Core	MSCI World Infra.	MSCI ACWI	UBS	UBS50-50
Panel F: 01/09–12/14								
H & K	7.3691	1.2262	0.3480	2.6625	3.0381	5.9643	3.5165	2.3387
p value	0.0013	0.2999	0.7074	0.0771	0.0546	0.0041	0.0353	0.1043
Stepdown1	11.0624	2.0731	0.6576	4.2455	2.3362	6.9264	6.9994	4.3885
p value	0.0014	0.1546	0.4203	0.0432	0.1311	0.0105	0.0102	0.0400
Stepdown2	3.2020	0.3734	0.0386	1.0304	3.6679	4.6012	0.0309	0.2753
p value	0.0780	0.5432	0.8448	0.3137	0.0597	0.0355	0.8610	0.6015

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index returns for the periods January 2000 to December 2008 and January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

these, only the Dow Jones Brookfield is found to improve the efficient frontier by the Kan and Zhou (2012) test.

Using total returns for the full sample period (Panel D of Table 10), all infrastructure indices examined reject the null of the Huberman and Kandel (1987) test at the 5% level; four still pass the Kan and Zhou (2012) test: the S&P Global Infrastructure, FTSE Macquarie Index, MSCI ACWI Capped Index, and the UBS 50-50 Index.

The same is true when the period January 2000 to December 2008 (Panel E of Table 10) is considered: all indices pass the Huberman and Kandel (1987) test and three (the FTSE Core, MSCI World Infrastructure, and MSCI ACWI Infrastructure) are found by the Kan and Zhou (2012) test to improve the tangency portfolio and the global minimum variance portfolio, with the remainder found to improve only the tangency portfolio.

However, from January 2009 to December 2014, only three of the eight portfolios pass the Huberman and Kandel (1987) test, and only one (the MSCI ACWI Capped Index) is found to improve the efficient frontier by the Kan and Zhou (2012) test on a total return basis.

6.2.3 US infrastructure indices

Table 11 shows the same results using US market indices and factors. For the full sample period and using price returns (Panel A of Table 11), the Alerian MLP Infrastructure Index is, again, the only index found to improve the efficient frontier according to the Huberman and Kandel (1987) test.

In the period from January 2000 to December 2008 (Panel B of Table 11), the Alerian MLP Infrastructure Index rejects the null hypothesis of the Huberman and Kandel (1987) test at the 5% level, but the Kan and Zhou (2012) test concludes that

Table 11 Results for the factor asset classes and US listed infrastructure indices with factor-based reference portfolios

	Alerian MLP	FTSE Macquarie USA	MSCI USA Infrastructure	MSCI USA Infrastructure Capped
Price returns				
Panel A: 01/00–12/14				
H & K	8.0362	1.0298	1.0553	0.1836
p value	0.0005	0.3613	0.3503	0.8324
Stepdown1	8.7670	0.0449	0.5795	0.2557
p value	0.0035	0.8326	0.4475	0.6137
Stepdown2	6.9949	2.0365	1.5348	0.1120
p value	0.0089	0.1571	0.2170	0.7383
Panel B: 01/00–12/08				
H & K	3.2144	1.3422	0.0637	0.6650
p value	0.0443	0.2909	0.9383	0.5165
Stepdown1	6.4173	0.0560	0.1059	0.6719
p value	0.0128	0.8161	0.7455	0.4143
Stepdown2	0.0109	2.7932	0.0216	0.6601
p value	0.9171	0.1141	0.8833	0.4184
Panel C: 01/09–12/14				
H & K	0.8072	0.1190	0.0891	0.0867
p value	0.4507	0.8880	0.9148	0.9171
Stepdown1	1.6137	0.0577	0.1382	0.0350
p value	0.2086	0.8109	0.7114	0.8523
Stepdown2	0.0007	0.1830	0.0407	0.1405
p value	0.9797	0.6702	0.8408	0.7090
Total returns				
Panel A: 01/00–12/14				
H & K	12.4051	0.9491	1.3303	0.1821
p value	0.0000	0.3910	0.2671	0.8337
Stepdown1	21.9107	0.1018	0.3802	0.3176
p value	0.0000	0.7505	0.5383	0.5738
Stepdown2	2.5900	1.8147	2.2886	0.0468
p value	0.1093	0.1814	0.1321	0.8289
Panel B: 01/00–12/08				
H & K	5.4190	0.9820	0.0060	0.5267
p value	0.0058	0.3974	0.9940	0.5921
Stepdown1	9.8783	0.0571	0.0001	0.0966
p value	0.0022	0.8144	0.9938	0.7565
Stepdown2	0.8830	2.0263	0.0121	0.9654
p value	0.3496	0.1738	0.9127	0.3282

Table 11 continued

	Alerian MLP	FTSE Macquarie USA	MSCI USA Infrastructure	MSCI USA Infrastructure Capped
Panel C: 01/09–12/14				
H & K	16.3809	0.8787	1.0270	1.6919
p value	0.0000	0.4201	0.3637	0.1921
Stepdown1	8.4217	1.2882	0.8764	0.9380
p value	0.0050	0.2605	0.3526	0.3363
Stepdown2	21.9127	0.4672	1.1798	2.4481
p value	0.0000	0.4966	0.2813	0.1224

Panel A presents the results for the Price-Index returns for the full sample period. Panels B and C present the results for the Price-Index returns for the periods January 2000 to December 2008 and January 2009 to December 2014, respectively. The total return spanning results are presented in Panels E, F, and G. Panel E reports the results for the full sample period. Panel F reports the results for the period January 2000 to December 2008, and Panel G reports the results for the period January 2009 to December 2014

only the tangency portfolio has improved. In the post-GFC period (Panel C of Table 11), similar conclusions hold.

Total returns for the full sample period (Panel D of Table 11) again show that only the Alerian MLP Infrastructure Index passes the Huberman and Kandel (1987) test, but the results of the Kan and Zhou (2012) test indicate that this is due to the Alerian MLP Infrastructure Index improving only the tangency portfolio.

From January 2000 to December 2008 (Panel E in Table 11), the conclusions are the same. However, for the period from January 2009 of December 2014 (Panel F of Table 11), the Alerian MLP Index passes both the Huberman and Kandel (1987) and Kan and Zhou (2012) tests, indicating that the efficient frontier has been improved.

Hence, the MLP Index is found to have a spanning profile somewhat similar to the PFI portfolio in the sense that it manages to create diversification benefits both before and after the GFC when considered from a total return perspective.

7 Conclusion

7.1 Summary of results

In this paper, we examined the contention that focusing on listed infrastructure has the potential to create diversification benefits previously unavailable to large investors already active in public markets. The reasons for doing so were threefold:

1. Several papers argue that this is the case but do not provide robust statistical tests of the hypothesis;
2. Index providers have created dedicated indices focusing on this idea and a number of active managers propose to invest in listed infrastructure, arguing that it constitutes an asset class in its own right, worthy of an individual allocation;

3. Capital–market instruments are used by investors to proxy investments in privately held (unlisted) infrastructure, but the adequacy of such proxies remains untested.

We tested the notion that there is a unique and persistent listed infrastructure effect using 22 listed infrastructure proxies and a series of statistical tests of mean–variance spanning against reference portfolios, built with either traditional asset classes or investment factors. We conducted these tests for global, US, and UK markets covering the past 15 years, on a price return and total return basis.

We conclude that *listed infrastructure*, as traditionally defined by SIC code and the industrial sector, *is not an asset class or a unique combination of market factors*, and, indeed, cannot be persistently distinguished from existing exposures in investors' portfolios. Expecting the emergence of a new or unique infrastructure asset class by focusing on public equities selected on the basis of industrial sectors is thus misguided.

Our test results are summarized in Table 12. The facts include:

1. We tested 22 proxies of listed infrastructure and found little to no robust evidence of a listed infrastructure asset class that was not already spanned by a combination of capital–market instruments and alternatives or a factor-based asset allocation.
2. The majority of test portfolios that improved the mean–variance efficient frontier before the GFC fail to repeat this feat post-GFC. There is no evidence of *persistent* outperformance.
3. Of the 22 test portfolios used in this paper to try to establish the existence of a listed infrastructure asset class, only four manage to improve on a typical asset allocation defined either by traditional asset class or by factor exposure after the GFC, and only one is not spanned both pre- and post-GFC. We return to these in the discussion below.
4. Building baskets of stocks on the basis of their SIC code and proportion of infrastructure income fails to generate a convincing exposure to a new asset class. A more promising avenue is to focus on underlying contractual or governance structures that tend to maximize dividend payout and pay dividends with great regularity, such as the PFI or MLP models.
5. More generally, benchmarking unlisted infrastructure investments with thematic (industry-based) stock indices is unlikely to be very helpful from a pure asset allocation perspective, that is, the latter do not exhibit a risk/return tradeoff or *betas* that large investors did not have access to already.

7.2 Discussion

While we conclude from testing the impact of 22 proxies that there is no convincing evidence of a listed infrastructure asset class, it is worthwhile to examine the four proxies that manage to improve on the proposed reference asset allocation *after* the GFC. Indeed, high pre-GFC Sharpe ratios that do not survive the 2008 credit crunch and lose all statistical significance in mean–variance spanning tests post-GFC do not make good candidates for an asset class or bundle of factors. However, proxies that pass the mean–variance tests after 2008 may at least open the possibility of a more persistent effect.

Table 12 Summary of mean–variance spanning tests

	Full sample	Pre-GFC	Post-GFC
Price returns			
50% Rev. Req. Telecom	×	×	×
50% Rev. Req. Transport	×	×	×
50% Rev. Req. Utilities	×	×	✓
75% Rev. Req. Telecom	×	×	×
75% Rev. Req. Transport	×	×	×
75% Rev. Req. Utilities	×	×	×
90% Rev. Req. Telecom	×	×	×
90% Rev. Req. Transport	×	×	×
90% Rev. Req. Utilities	×	×	×
Alerian MLP	✓	×	×
FTSE Macquarie USA	×	×	×
MSCI USA	×	×	×
MSCI USA Infra. Capped	×	×	×
DJ Brookfield Global	✓	×	✓
S&P Infrastructure	×	✓	×
FTSE Macquarie Infra.	×	×	×
FTSE Global Core	×	×	×
MSCI World Infra.	×	✓	×
MSCI ACWI Infra. Capped	×	×	×
UBS Global Infra. Uti.	✓	✓	×
UBS Global 50-50	×	×	×
PFI Portfolio	×	×	×
Total returns			
50% Rev. Req. Telecom	×	×	×
50% Rev. Req. Transport	×	×	×
50% Rev. Req. Utilities	×	×	×
75% Rev. Req. Telecom	×	×	×
75% Rev. Req. Transport	×	×	×
75% Rev. Req. Utilities	×	×	×
90% Rev. Req. Telecom	×	×	×
90% Rev. Req. Transport	✓	×	×
90% Rev. Req. Utilities	×	×	×
Alerian MLP	×	×	✓
FTSE Macquarie USA	×	×	×
MSCI USA	×	×	×
MSCI USA Infra. Capped	×	×	×
DJ Brookfield Global	✓	×	✓
S&P Infrastructure	✓	✓	×
FTSE Macquarie Infra.	✓	✓	×

Table 12 continued

	Full sample	Pre-GFC	Post-GFC
FTSE Global Core	×	✓	×
MSCI World Infra.	×	✓	×
MSCI ACWI Infra. Capped	✓	✓	✓
UBS Global Infra. Uti.	✓	✓	×
UBS Global 50-50	✓	×	×
PFI Portfolio	✓	×	✓

This table summarizes the findings of the mean–variance spanning tests for the infrastructure proxies and different asset allocation strategies employed in this paper. ✓ indicates that the infrastructure proxy passed all three spanning tests at the 5% confidence level either with reference to an asset class-built portfolio or a factor-built portfolio. The first column reports results for the whole sample from 2000 to 2014, the next two columns report pre- and post-GFC results, and the fourth column highlights the proxies that show post-GFC persistence of pre-GFC improvement in the efficient portfolio frontier

The four proxies that are not already spanned by our reference portfolios in the post-GFC period questions are:

1. The Brookfield Dow Jones Infrastructure Index: Close examination reveals that this index made a significant shift toward the oil and gas sector after the GFC and benefited from the significant rise in oil prices in the subsequent period. We note, without further investigation, that since 2014 and the collapse of global oil prices, it has experienced lackluster performance. Hence, rather than an infrastructure effect, this proxy may have been capturing a temporary oil play.
2. The MSCI ACWI Infrastructure Capped: This proxy is the only one that passes the spanning tests both pre- and post-GFC. In fact, it is one of the few listed infrastructure indices that is not simply weighted by market capitalization but is instead constrained to have a maximum of one-third of its assets invested in telecoms, one-third in utilities, and another third in energy and transportation. Hence, it uses a very ad hoc weighing scheme, vaguely resembling equal weighting, which nevertheless improves on the market-cap-weighted point of reference. Again, rather than an effect driven by an elusive infrastructure asset class, it seems reasonable to assume that portfolio weights explain the impact of this proxy.[15]
3. The Alerian MLP Index: This proxy and the next one only improve the reference allocation post-GFC on a total return basis. Here, the role played by dividend payouts, their size, and regularity relative to other stocks are likely explanations for why they succeed in passing the spanning tests.
4. The PFI Portfolio: The proxy corresponds to self-contained investment vehicles which receive a steady income stream from the public sector. While these firms have risky but essentially fixed and predictable operating and financing costs, by design, these firms are likely to have very regular dividend payouts and the more "bond-like" characteristics often associated with infrastructure investment.

[15] In future research, a similar test of mean–variance spanning against efficient or "smart" reference indices is necessary to control for such effects.

This last point is important since the observed improvement in the efficient frontier by adding assets such as MLPs or PFIs also corresponds to the beginning of the very low interest rate policies introduced by US and UK central banks after the GFC.

In such an environment, such high-coupon-paying assets start to exhibit previously unremarkable characteristics that mechanically increase their ability to have an impact on the reference portfolio.

Crucially, what determines this ability to deliver regular and high dividend payouts is the contractual and governance structure of the underlying businesses, not their belonging to a given industrial sector.

However, it must be noted that the relatively low aggregate market capitalization of listed entities offering a clean exposure to infrastructure business models as opposed to infrastructure industrial sectors may limit the ability of investors to enjoy these potential benefits unless the far larger *unlisted* infrastructure fund universe has similar characteristics.

We conclude that *as an asset selection scheme*, the notion of investing in infrastructure should be understood as a *heuristic*, that is, a mental shortcut meant to create an exposure to certain factors, but neither a thing nor an end in itself.

A clear distinction can be made between infrastructure as a matter of public policy, in which case the focus is rightly on industrial functions, and the point of view of financial investors, who may be exposed to completely different risks through investments in firms providing exactly the same industrial functions. Notional grouping of assets by industrial sectors (transport, energy, water, etc.) creates very little information or predictive power.

Focusing on definitions of infrastructure investment that match the tangible or industrial characteristics of certain firms or assets is unhelpful because it does not take into account the mechanisms that create the potentially desirable characteristics of infrastructure investment. Infrastructure investment should be construed solely as a way to buy claims on future cash flows created by specific underlying business models, themselves the product of long-term contractual arrangements between public and private parties (or, alternatively, between two private parties).

It follows that infrastructure investment, listed or not, is much more likely to play a role in an ALM framework than in a pure asset allocation setting (mean–variance optimization) where there are more relevant building blocks for designing investment policies.

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Appendix

1. Reference assets

Table 13 Descriptive statistics of annualized price and total returns of (**Panel A**) the global reference asset classes. (**Panel B**) Descriptive statistics of annualized price and total returns of the US reference asset classes. (**Panel C**) Descriptive statistics of annualized price and total returns of the UK reference asset classes, 2000–2014

	Bonds	Real estate	Commo.	Hedge funds	OECD stocks	EM stocks
Panel A						
Price returns						
Price return	0.055	0.015	0.022	0.062	−0.001	0.016
Risk	0.058	0.200	0.236	0.057	0.161	0.234
SR	0.845	0.051	0.073	0.990	−0.037	0.048
Total returns						
Tot. return	0.055	0.054	−0.019	0.063	0.023	0.044
Risk	0.058	0.199	0.239	0.057	0.161	0.234
SR	0.845	0.246	−0.101	1.025	0.109	0.165

	Gov. bonds	Corp. bonds	High yield	Real estate	Commo.	Hedge funds	US stocks	World ex-US
Panel B								
Price returns								
Price return	0.013	0.011	−0.006	0.063	0.010	0.065	0.029	0.004
Risk	0.041	0.034	0.098	0.057	0.234	0.219	0.157	0.174
SR	0.197	0.170	−0.113	1.026	0.023	0.271	0.155	−0.007
Total returns								
Tot. return	0.055	0.058	0.081	0.065	0.010	0.119	0.048	0.033
Risk	0.042	0.035	0.100	0.057	0.234	0.220	0.157	0.174
SR	1.178	1.500	0.755	1.060	0.023	0.518	0.274	0.157

	Fixed interest	Real estate	Hedge funds	Commo.	UK stocks	World ex-UK
Panel C						
Price returns						
Price return	0.059	0.031	0.049	0.013	−0.004	0.020
Risk	0.050	0.207	0.121	0.217	0.142	0.155
SR	1.076	0.122	0.361	0.035	−0.060	0.097
Total returns						
Tot. return	0.059	0.066	0.051	0.013	0.031	0.043
Risk	0.050	0.208	0.121	0.217	0.142	0.155
SR	1.078	0.290	0.376	0.035	0.181	0.243

2. Reference investment factors

Table 14 Descriptive statistics of annualized price and total returns of (**Panel A**) the global reference factors. (**Panel B**) Descriptive statistics of annualized price and total returns of the US reference factors, 2000–2014

Panel A	Market (EUR)	Market (US)	Size	Value
Price returns				
Price return	−0.034	−0.011	0.052	0.025
Risk	0.196	0.156	0.071	0.095
SR	−0.200	−0.099	0.659	0.210

	Market (EUR)	Market (US)	Size	Value	Term	Default
Total returns						
Tot. return	−0.003	0.008	0.047	0.042	0.039	−0.007
Risk	0.196	0.156	0.072	0.095	0.076	0.227
SR	−0.041	0.022	0.579	0.390	0.442	−0.052

	Market	Size	Value	Term	Default
Panel B					
Price returns					
Price return	0.016	0.027	0.029	−0.002	−0.024
Risk	0.159	0.106	0.114	0.087	0.068
SR	0.070	0.208	0.209	−0.082	−0.428
Total returns					
Tot. return	0.035	0.022	0.043	0.055	0.033
Risk	0.159	0.106	0.114	0.087	0.068
SR	0.187	0.156	0.331	0.572	0.411

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