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Diversification benefits of Listed Infrastructure

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Abstract

According to the infrastructure investment narrative, infrastructure is less exposed to business cycles and less affected by short term events, implying a potential diversification benefit in a mixed asset portfolio. Does the same characteristics hold for listed infrastructure? And should listed infrastructure be treated as a separate asset class? This paper seeks to answer those questions through a comprehensive analysis consisting of a mean-variance portfolio optimization, a mean value-at-risk optimization and a mean-variance spanning test. Weekly return indices from Bloomberg spanning from 2003 to 2016 was used in the analysis. This paper is not supportive of the claims that listed infrastructure should be treated as a separate asset class, nor that it improves the mean-variance trade-off in a global mixed asset portfolio.

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1.0. Introduction

In May 2017 FTSE Russel wrote in their insights paper *meeting the demand for listed infrastructure indexes* that “market participants may use infrastructure indexes as diversification tools for global investment portfolios”. They proceed the paper by explaining the unique characteristics of infrastructure and why some investors might benefit from investing part of their portfolio in infrastructure. FTSE is not alone in suggesting the uniqueness of infrastructure investments. In fact, Thomson Reuters, Dow Jones, MSCI and Standard & Poor´s have all made dedicated infrastructure indices. There has also been a steady rise in the number of unlisted infrastructure funds during the last decade. From 2007 to 2017 the number of unlisted infrastructure funds have grown from 47 to 181 (Preqin, 2017).

Whether listed infrastructure constitutes the same unique characteristic as unlisted direct investments in infrastructure has been the subject of numerous research papers, and some authors have also examined the role of listed infrastructure in investment portfolios. However, research prior to this paper has not produced unambiguous results regarding the diversification benefits of listed infrastructure. While Peng and Newell (2007) and Oyedele (2013) finds evidence supporting a potential diversification benefit, studies such as Idzorek and Armstrong (2009) and Martin (2010) does not support this claim. One drawback with previous studies on listed infrastructure is that they focus on global infrastructure as a whole or in one specific country, not considering the potential variety among different listed infrastructure sectors and markets. As a result, there is little research on the economic characteristics among different types of listed infrastructure.

With that in mind, this paper seeks to compliment the prior research done on listed infrastructure and the potential diversification benefits obtained by including listed infrastructure in a mixed asset portfolio. To scrutinize the subject, we have not only used the Markowitz mean-variance portfolio optimization methodology used by most prior papers on the subject, but we also conducted a mean-variance spanning test examining the statistical significance of the mean-variance trade-off after listed infrastructure is included in the investment opportunity set. We have also conducted a mean-conditional value-at-risk analysis as a robustness check of the results given by the mean-variance optimization. Our data sample consists of weekly returns spanning from 2003 to 2016 capturing both stable macroeconomic conditions and times of financial distress. In addition to the diversification potential of listed infrastructure, we address the question of whether listed infrastructure constitutes an own asset class by comparing different listed infrastructure sectors and markets. If listed infrastructure is an own asset class, we should find similarities in both historical performance and high correlation across sectors and markets. Despite finding evidence of exceptional performance in terms of high annualized returns during the period of our data sample, this paper does not find evidence supporting the claim that listed infrastructure constitutes unique characteristics making it an ideal diversification tool in a mixed asset portfolio. The variety in both sector performance and market performance of listed infrastructure suggest that listed infrastructure does not constitute a unique asset class.

The rest of the paper is structured as follows: In section 2 we present previous research regarding infrastructure performance and portfolio optimization. Section 3 describes performance measures and framework of the test used in this paper. Section 4 presents a description of our data set. In section 5 our empirical results are presented. Finally, we summarize and conclude in section 6.

1.1 Defining Infrastructure

Despite little controversy regarding the importance of infrastructure as a crucial input for economic productivity and development, there is no unanimous definition of the term. Linguistically the word “infrastructure” is a combination of the Latin word “infra” meaning “below” and “structure”, expressing a form of “foundation” (Buhr, 2003). Stohler (1964) defines infrastructure as the substructure or the “skeleton” asset of an economy. Reimut Jochimsen (1966) stated that “infrastructure is defined as the sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of a suitable allocation of resources”. Nowadays infrastructure is sometimes divided into social and economic subgroups, or “core” and “non-core” infrastructure. Economic infrastructure includes transportation, energy/utility and communication facilities (core), while social infrastructure is seen as a medium for supplying basic services to households such as healthcare, education and judicial facilities (non-core) (Finkenzeller et al., 2010). Baldwin & Dixon (2008) divides core infrastructure by their functions into three categories: 1) Transportation and communication that allow people in geographically distant areas to interact with one another. 2) Transportation, communication, water and sewage that allows for the concentration of many people in the same area, and 3) Electricity and power which is a universal input. All activities use energy in some form or other. They argue that since most categories of core infrastructure exists to facilitate relationships among people, either at a distance or in close quarters, infrastructure capital is seen to be a facilitator for activities that are central to the economy, and to society. To analyse the characteristics of listed infrastructure we have decided to rely on the sector methodology given by Dow Jones Brookfield. They have made seven sector specific indices and three market specific indices of listed infrastructure. They divide infrastructure into the follow sectors: Water, Ports, Telecommunication, Electricity, Oil and Gas Storage, Toll Roads and Airports. The market specific indices consist of North American listed infrastructure, European listed infrastructure and Asian Pacific listed infrastructure.

2.0. Literature review

In the beginning, the main contribution of research papers was related to whether listed infrastructure had different characteristics than traditional assets, such as Stocks and Bonds, and whether listed infrastructure could be classified as a separate asset class. Fabozzi and Markowitz (2011) define asset classes as highly correlated homogenous investments with comparable characteristics, driven by similar factors, and with a common legal and regulatory structure. To obtain an adequate diversification benefit it is important to include different types of asset classes in a portfolio. The infrastructure investment narrative presented in Blanc-Brude (2013) presents a set of investments beliefs commonly held by investors about the characteristics of infrastructure investments. According to these beliefs infrastructure investments are less exposed to business cycles due to low price volatility, and they should be less impacted by current events as the value of such investments are expected to be mostly determined by stable income streams extended far into the future. Therefore, our paper will start by addressing whether listed infrastructure should be treated as an asset class by analysing different listed infrastructure sectors on a global level.

Peng & Newell (2007) investigated the performance and diversification benefit among Australian infrastructure by assessing listed infrastructure funds, listed infrastructure companies and unlisted infrastructure funds. They stated that listed Australian infrastructure performed both higher returns and volatility than traditional assets, whilst not being highly correlated with other assets, confirming their diversification benefit. They also found that infrastructure gave a higher Sharpe ratio and growing correlation with other assets over time. Where as they in another paper assessed the performance and diversification benefits of listed infrastructure in the US (Newell & Peng, 2008). Confirming that listed infrastructure in the US has no enhanced risk-adjusted performance compared to other traditional assets, and no improved correlation towards other assets, which indicate no significant diversification benefits in a mixed asset portfolio. As one of the key incentives for investing in infrastructure are claimed to be differences in risk profile compared with more traditional assets, Rothballer and Kaserer (2012) tested the risk characteristics of 1400 infrastructure stocks. They stated that listed infrastructure on a global level delivers lower market risk than comparable equities in the MSCI All Country World Index, confirming the diversification benefits, but do not provide a lower corporate risk than other pubic equities. These papers all state mixed results in the sense that some authors finds that listed infrastructure perform better than other assets and has diversification benefits, where as other claims that there is no benefits of investing in infrastructure. Furthermore, all these papers look at infrastructure in a specific market or at a global level using data prior to 2009, and only document potential benefits by ranking each asset after their Sharpe ratio and look at how each asset correlate with each other to document potential diversification benefits. As such, our empirical strategy and contribution to these papers will be to use infrastructure indices with a required level of revenue from infrastructure related operations, and then separate infrastructure into different markets (North America, Europe, Asia-Pacific) and sectors to see whether it is necessary to be exposed on a global level and distinguish if infrastructure as an asset should be treated as a whole.

Our paper is more related to empirical papers that have used listed infrastructure indices as a proxy for their performance, and used Modern Portfolio Theory to construct their portfolios. Using indices, Finkenzeller, Decant, & Schäfers (2010) used a Mean-Semivariance approach to see if Australian infrastructure in a mixed asset portfolio would enhance benefit of diversification. Decan & Finkenzeller (2013) later performed a similar analysis, now with a Mean-Variance approach, where they looked into the US infrastructure market. Where as Oydele, Adair, & McGreal (2014) examined the Global infrastructure market as a whole. All these research papers concluded that infrastructure provide a diversification benefit in a mixed asset portfolio.
All these papers contributed with the inclusion of Modern Portfolio Theory, and concluded that infrastructure had a diversification benefit in a portfolio consisting of traditional assets. Also, this paper will use Mean-Variance as an approach to construct portfolios as earlier studies. However, financial data tend to exhibit fat tails and skewed distributions. Therefore, we introduce an optimization technique called Mean-Conditional Value at Risk, which do not assume normal distribution

such as Markowitz´s Mean-Variance optimization. This technique will be used a robustness check for the Mean-Variance optimization.

In absence of previous research papers, Oydele, McGreal, Adair, & Ogedengbe (2013) introduced the first paper regarding European infrastructure performance in a mixed asset portfolio, with the same optimization techniques as previous studies. They concluded that European infrastructure improved the results for a portfolio, however, they also specified that infrastructure works more as a “risk amplifier” than a “risk reducer” in a portfolio.

Most relevant research to our paper is Bianchi, Bornholt, Drew & Howard (2014) research of the infrastructure market in USA, where they analysed whether infrastructure can improve the efficient frontier of a portfolio existing of traditional assets. Their contribution to earlier research was to include a Mean-Conditional Value at Risk optimization to see if this technique resulted in different portfolio weights than Mean-Variance. They fine that infrastructure has the same market trends as the stock market, but that infrastructure provides higher returns, lower tail-risk (CVaR), and higher Sharpe ratios. Hence, leading to an improved efficient frontier for their Mean-Conditional Value at Risk and Mean-Variance analysis. They also found that it was no significant different whether they used Mean-Conditional Value at Risk or Mean-Variance optimization. On this behalf, this paper will use this framework as a robustness check, in addition to add different infrastructure sectors and markets.

Prior research papers related to this topic have so far not elaborated whether listed infrastructure has a significant impact on a portfolio consisting of traditional assets. Hence, it still remains unclear whether using listed infrastructure in a mixed asset portfolio can create a diversification benefit. On this behalf, this paper separate infrastructure into different markets and sectors, and empirically run a Mean-Variance Spanning Test to analyse whether listed infrastructure creates a significant diversification benefit, and if infrastructure´s characteristics can be analysed as a whole need to be separated.

3.0. Methodology

To answer the questions *"is listed infrastructure an asset class?"* and *"does listed infrastructure improve the mean-variance trade-off in a mixed asset portfolio*?" we base our analysis on the following methodology:

Harry Markowitz (1952) introduced and revolutionized the risk management approach by introducing his mean-variance-portfolio optimization technique, which today is a well-known approach within modern portfolio theory. The mean-variance approach enables us to form a variety of portfolios consisting of Stocks, Bonds, Real Estate, and Infrastructure. For each portfolio, the weighted average return can be expressed as:

$$E[w^T r] = \sum_{i=1}^{N} w_i \times r_i,$$

where ***w*** is the weighted distribution invested in asset *i*, and *r* is the expected return. If an investor should have an incentive to combine multiple assets this should reduce the risk as opposed to investing in only single assets. The standard deviation associated with each portfolio is defined as

$$\sigma(w^T r) = \sqrt{Var(w^T r)} = \sqrt{w^T \Sigma w},$$

where ∑ is the covariance matrix of assets returns =

$$\begin{pmatrix} Var(r_1) & Cov(r_1, r_2) & \dots & Cov(r_{1,}, r_n) \\ Cov(r_2, r_1) & Var(r_2) & \dots & Cov(r_2, r_{n)} \\ \vdots & \vdots & \ddots & \vdots \\ Cov(r_n, r_1) & Cov(r_n, r_2) & \dots & Var(r_n) \end{pmatrix}$$

The formulas show that the volatility of the portfolio depends on the variance of all assets, plus the covariance between them. To spread the risk, an investor should hold a portfolio where the assets are not perfectly correlated with each other. The lower the correlation between assets, the greater the diversification effect is. In other words, the risk can be reduced without having a negative effect on the expected return.

Using Markowitz Mean-Variance portfolio theory each portfolio can be formed by solving:

$$\min_{w} \quad w^T \Sigma w$$

$$s.t \quad 1)\; w^T \hat{r} \geq R$$

$$2)\; w_i \geq 0$$

$$3)\; \sum_{i=1}^{N} w_i = 1,\; 1 = 1, 2..., N$$

The minimization equation above will be used to construct a set of portfolios with the required rate of return at the lowest possible risk. However, each portfolio need to satisfy three constraints; 1) the portfolios expected return need to be higher or equal to the target return (R), 2) no short selling of any asset, 3) the budget constraint needs to sum up to 1. All portfolios constructed will lie on the so-called efficient frontier which represents the set of portfolios that generate the best risk-return trade-off between the assets.

A drawback with Markowitz optimization technique is the assumption of normal distribution of returns. Meaning that standard deviation is taken to be a fully adequate measure of risk, and since standard deviation is measured in either direction will not tail losses arising from skewed loss distributions be taken into account. Potential non-normality of return requires us to pay extra attention and focus on worst-case scenario losses. On this behalf, we will introduce a second optimization technique called Mean-Conditional Value at Risk. Mean-Conditional Value at Risk optimization technique was first introduced by Rockafellar and Uryasev (2000) and is used to measure the tail-risk for a portfolio, and it does not assume normal distribution for the returns, such as Markowitz optimization theorem. The efficient frontier constructed will be compared with Markowitz Mean-Variance approach to check their robustness. With Mean-Conditional Value at Risk technique we are able to calculate the highest returns obtainable for a given level of conditional value at risk (CVaR) at 95% confidence level. Conditional Value at Risk for each portfolio is defined as:

$$CVaR_\alpha(x) = \frac{1}{1-\alpha} \int_{f(x,y) \geq VaR_{\alpha(x)}} f(x,y)p(y)dy$$

where $\boldsymbol{\alpha}$ is defined as any specified probability level between 0 and 1, $\boldsymbol{f(x,y)}$ is the loss function for a random vector $\boldsymbol{x}$ that is representing a portfolio and $\boldsymbol{y}$ represents a vector for asset return, and ***p(y)*** is the probability density function for asset return $\boldsymbol{y}$.

$VaR_{\alpha(x)}$ is defined at the value at risk for portfolio $\boldsymbol{x}$ at a probability level α, and is given by:

$$VaR_{\alpha}(x) = min\{c : \psi(x,c) \geq \alpha\},$$

where $\psi(x,c)$ is the probability of $f(x,y)$ not exceeding the threshold *c*.

By constructing Mean-Variance and Mean-Conditional Value at Risk portfolios we are able to compare both efficient frontiers and the weight distribution of selected assets.

To examine the possible diversification benefits of listed infrastructure, we construct cross-asset correlation matrices for both the sector analysis and the market analysis. With two assets (a and b) the correlation is given by:

$$\rho_{a,b} = corr(a,b) = \frac{cov(a,b)}{\sigma_a \sigma_a}$$

For three assets (a, b and c), the correlation matrix (R) is given by:

$$R = \begin{bmatrix} \rho_{a,a} & \rho_{a,b} & \rho_{a,c} \\ \rho_{a,b} & \rho_{b,b} & \rho_{b,c} \\ \rho_{a,c} & \rho_{b,c} & \rho_{c,c} \end{bmatrix}$$

After the portfolios are constructed performance measures including Sharpe ratio, Modigliani risk-adjusted performance (M^2), and Mean-Variance Spanning Test are calculated. This will be used to see if the inclusion of infrastructure might improve the performance of a portfolio.

The Sharpe Ratio (Sharpe, 1966), also known as "reward-to-variability" ratio, is a "risk-adjusted" performance measure, measuring the average return is excess of the risk-free rate per unit of risk. It is calculated by dividing the average return of an asset minus the risk-free rate with the standard deviation of that asset (Sharpe, 1994). By subtracting the risk-free rate from the average return, we are isolating the risky return on that asset. The formula is given by:

$$S_i = \frac{R_i - R_f}{\sigma_i}$$

Where:

R_i = Return on portfolio *i*

R_f = Risk-free rate

σ_i = Standard deviation of portfolio *i*

A drawback with The Sharpe Ratio is that it only gives a pure numerical number for the risk-return relationship, and when the returns are negative it is hard to interpret. Modigliani risk-adjusted performance (M^2) developed by Franco Modigliani and Leah Modigliani (1997) measures portfolio return for a given amount of risk, relative to the market portfolio. Hence, it measures by how much the portfolios outperform or underperform in percentage relative to the market portfolio. The formula is given by:

$$M^2 = \left(\frac{R_i - R_f}{\sigma_i} - \frac{R_m - R_f}{\sigma_m}\right) \times \sigma_m$$

Where:

R_i = Return on portfolio *i*

R_m = Return of the market portfolio *m*

R_f = Risk-free rate

σ_i = Standard deviation of portfolio *i*

σ_m = Standard deviation for the market portfolio *m*

In addition to correlation matrices, we use the methodology by Huberman and Kandel (1987) to measure the potential diversification benefits of listed infrastructure. The Mean-Variance Spanning test estimates whether the mean-variance efficient frontier of a set of K benchmark assets is the same as the mean-variance efficient frontier of the K benchmark assets plus N additional test assets. We start with an investor that currently only invests in a global base portfolio of traditional stocks, bonds and real estate (K). Then, we consider two different diversification opportunities (N):

A = Sector diversification
B = Global diversification

In opportunity A, we allow the investor to optimize the portfolio weights based on the seven listed infrastructure subsector indices. In opportunity B, the same optimization is based on the three market indices of listed infrastructure. For each type of diversification, we measure the mean-variance improvement by adding one listed infrastructure asset to the optimized base portfolio.

The spanning test is estimated as an ordinary least squares regression with a regression intercept. If the intercept is significantly different from zero (and positive), it means that inclusion of the test asset in the optimal base portfolio improves the mean-variance trade-off. Alpha = 0, and beta = 1 means that that inclusion of the test asset (K + N), span the benchmark (K) portfolio so there is no significant shift in the frontier. For both the test assets and the benchmark portfolio the regression is based on excess returns (mean return – risk free rate).

The ordinary least squares regression is given by:

$$r_t^y = \alpha_t + \beta r_t^x + \varepsilon_t^x$$

r_t^x = T x K matrix of excess return on the benchmark portfolio

r_t^y = T x N matrix of excess return on the test asset

a_t = regression intercept

β = K x N regression matrix of regression factor loadings.

ε_x = regression error term

4.0. Data

Historical data obtained from Bloomberg and Thomson Reuters database includes weekly returns in US dollars for the period 2003 to 2016. Returns for each index are raw returns adjusted for dividends, hence each stock closing price is adjusted for dividends and other corporate events.

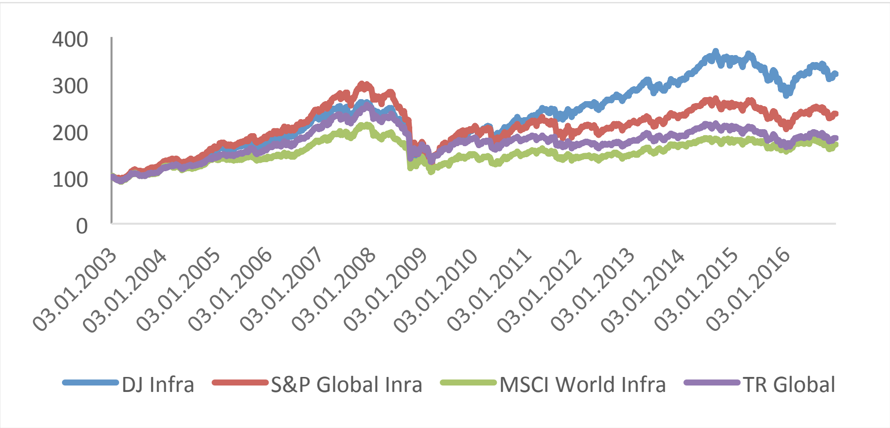
As a proxy for the global stock market we use **MSCI World Equity Index**, which is a free float-adjusted market capitalization index based on the Global Investable Indices Methodology (GIMI). With 1 652 constituents, this index captures large and medium capital companies in 23 Developed Markets countries, and is rebalanced quarterly.

Barclays Bond Composite index is used to reflect the trend within the largest capitalization bonds in the three major markets EU, Japan and USA. This index is composed of government bonds, corporate bonds, and mortgage-backed bonds.

MSCI World Real Estate index will be used to as a proxy for the global real estate market. It is also a free float-adjusted market capitalization index that consists of large- and medium-cap equity across 23 Developed Markets.

For infrastructure there is a varied range of indices available. Thomson Reuters, MSCI, FTSE, S&P, and Dow Jones Brookfield all provide infrastructure indices to assess the performance of listed infrastructure. How each provider define infrastructure and construct their indices based on industry and country may differ, and hence influence the results. Figure 1 gives an indication on how different each index performed from 2003 – 2016.

Figure 1: Performance 2003 – 2016 infrastructure indices



We have chosen to use **Dow Jones Brookfield Infrastructure** as a proxy for infrastructure performance, since they provide indices for both the largest continents and different sectors within infrastructure. All indices are constructed based on Brookfield Asset Management's definition of infrastructure as an asset class, which are long-life assets that generate stable and growing cash flow. To be included in the index for different continents (North America, Europe, Asia-Pacific), all companies must obtain at least 70% of the operating cash flow from infrastructure related business. For the global sector indices, each company also need to derive at least 70% of cash flow from infrastructure lines of business, but over 50% of cash flow need to come from indicated sector. Seven different infrastructure sectors have been used to measure and analyze whether there is a difference in infrastructure sectors performance: Electricity distribution & transmission management[1], Airports[2], Water[3], Ports[4], Communication[5], Toll Roads[6] and Oil & Gas Storage[7].

The indices for the continents includes and measures the performance for over 100 infrastructures companies worldwide, where 48 companies are located in North America, 27 in Europe, and 26 in Asia-Pacific. Whereas for infrastructure sectors all indices in total generate a total market capital of $923 billion, distributed over 94 companies.

The market capital and sector distribution among the indices used for the market analysis are somewhat unequal distributed (Appendix 1). This is something we need to be aware of since each continent and sector might be exposed to different macroeconomic factors, which furthermore affect our results.

[1] Electricity distribution & transmission management, excluding revenues from generation, exploration and production of energy products

[2] Including development, ownership, lease, concession, or management of airports and related facilities

[3] Water related infrastructure, including water distribution, wastewater management, and purification/desalination

[4] Seaports and related facilities

[5] Including broadcast/mobile towers, satellites and fibre optic/copper (excluding telecom services) cables

[6] Development, ownership, lease, concession or management of toll roads and related facilities

[7] Including oil & gas (and other bulk liquid products) fixed transportation or storage assets and related midstream energy services

Normal distribution is an important precondition behind many theories within finance. For example, standard deviation is only a valid risk measure as long the returns are normally distributed. As we see from the descriptive statistics, all indices have skewed distributions and high kurtosis, which means that tail losses are not taken fully into account and could lead to spurious results (Appendix 2). The Jarque-Bera test is based on a null hypothesis that a data samples returns are normally distributed. As the descriptive indicate, none of the indices are normally distributed. A solution to this problem could be to use log-returns instead of simple returns, but this does not solve our non-normality problem. Actually, log-returns give a higher Jarque-Bera (Appendix 2).

5.0. Results

This section is separated into four parts to get a better understanding of infrastructure´s behaviour both as a separate asset and in a portfolio. First, a separated performance analysis of each asset class is elaborated to see how infrastructure perform over a longer period and in different market conditions, compared with traditional assets such as Stocks, Bonds, and Real Estate. Then a Mean-Variance optimization is conducted to construct a varied range of portfolios to see whether the inclusion of infrastructure in a mixed asset portfolio can improve the risk-return trade-off and the efficient frontier for a portfolio consisting of Stocks, Bonds, and Real Estate. In the third section a Mean-Conditional Value at Risk analysis is implemented to check the robustness of our Mean-Variance results. Finally, a Mean-Variance Spanning Test is conducted to see if infrastructure has a statistically significant Mean-Variance improvement on the benchmark portfolio.

5.1. Performance analysis

5.1.1. Sector performance

Table 1 shows the performance of infrastructure sectors and traditional assets for the overall period. The difference in sector performance for infrastructure during the overall period gives an indication of that infrastructure should not be treated as a single asset class. For example, Communication had the best performance with an annual return of 32% and a volatility of 25.91%, while Ports performed worst with an annual return of 8.73% and a volatility of 20.63%. Comparing all assets, it is a clear variation of the performance among them, which indicates that they all are affected by very different macroeconomic factors. Despite the high return and volatility for infrastructure sectors, they all had had a better risk-return trade-off, except Ports, compared to Stocks and Real Estate. Takeaway from this section from an investor's point of view, it is important to know the different characteristics between each sector before they invest, since they all perform at a very different level.

Table 1: Performance infrastructure sectors

2003 - 2016	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Electricity	7.65	15.49	0.42	6
Airports	15.10	20.60	0.67	3
Water	10.22	18.78	0.48	5
Ports	8.73	28.36	0.27	10
Communication	32.00	25.91	1.19	1
Toll Roads	8.68	20.63	0.36	7
Oil&Gas	9.94	16.26	0.54	4
MSCI World Equity	6.73	17.10	0.32	9
Barclays Global Bond	4.28	4.41	0.70	2
MSCI Word Real Estate	8.30	20.17	0.35	8

Before the Global Financial crisis

Table 2 shows the performance for infrastructure and traditional assets for a stable economical period from 2003 - 2006. With an average annual return of 81.95% communication had an exceptional return during this period. Despite having the highest annualized volatility of 25.47%, communication also outperformed all other assets with a risk-return trade-off of 2.70. Among the infrastructure sector, the worst performing sector was electricity with an average annual return of 15.61% and an annualized volatility of 11.67%. In terms of the risk-return trade-off all infrastructure sectors, except electricity, outperformed Stocks in this period.

Table 2: Performance infrastructure prior GFC

2003 - 2006	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Electricity	15.61	11.67	1.12	9
Airports	27.23	15.75	1.57	6
Water	25.07	13.63	1.65	5
Ports	38.09	18.50	1.92	3
Communication	81.95	29.44	2.70	1
Toll Roads	26.88	12.99	1.87	4
Oil&Gas	17.04	10.41	1.39	7
MSCI World Equity	15.38	11.42	1.12	8
Barclays Global Bond	4.54	4.46	0.44	10
MSCI Word Real Estate	26.86	12.45	1.95	2

During the Global Financial crisis

Table 3 shows the performance for all assets from 2007 -2009, highlighting the performance during a period with high financial distress. Compared with the bullish market tendencies from 2003 – 2006 all assets, expect Bonds, over doubled their volatility. Real Estate was the asset that was harmed worst, mainly since the crisis was caused by a collapse in the Real Estate market. The results from this bearish period indicate that listed infrastructure sectors follow the same market trends as Stocks and Real Estate considering the increase in volatility and decrease in return. Once again, Communication outperforms all infrastructure sectors with a Sharpe ratio of 0.30. The sector with the worst performance is Water with an average annual return of -8.69 and annualized volatility of -29.75%%, rendering a Sharpe ratio of -0.37.

Table 3: Performance infrastructure sectors during GFC

2007 - 2009	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Electricity	-0.01	23.61	-0.08	5
Airports	2.58	31.92	0.02	4
Water	-8.89	29.75	-0.37	10
Ports	-4.60	48.31	-0.14	7
Communication	13.18	37.44	0.30	2
Toll Roads	-1.52	30.12	-0.12	6
Oil&Gas	4.12	23.41	0.09	3
MSCI World Equity	-3.25	26.19	-0.20	8
Barclays Global Bond	6.54	5.12	0.89	1
MSCI Word Real Estate	-10.02	34.07	-0.35	9

After the Global Financial Crisis

Table 4 shows the performance of global infrastructure sectors from 2010 - 2016. In this period, all infrastructure sectors had recovered from the global financial crisis, except ports, in terms of positive Sharpe ratios. The results indicate a clear change in terms of performance for infrastructure sectors compared with the pre-crisis period 2003 - 2006. All infrastructure sectors have a lower annual return and lower Sharpe ratios compared with the pre-crisis period. Thus, compared with the

Stocks and Real Estate assets infrastructure sectors such as Airports, Communication, Water, Oil & Gas, and Electricity in this period perform better in terms of the risk-return trade-off.

Table 4: Performance infrastructure sectors post GFC

2010 - 2016	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Electricity	6.39	12.81	0.49	6
Airports	13.54	16.47	0.82	1
Water	9.92	14.79	0.66	4
Ports	-2.33	20.28	-0.12	10
Communication	11.53	15.36	0.74	3
Toll Roads	2.66	19.09	0.13	9
Oil&Gas	8.38	15.27	0.54	5
MSCI World Equity	6.06	14.74	0.40	7
Barclays Global Bond	3.17	4.04	0.76	2
MSCI Word Real Estate	5.54	15.01	0.36	8

Cross-sector correlation

By calculating the correlation among all assets, a potential diversification benefit among listed infrastructure sectors and their relation towards other asset classes can be evaluated. The cross-sector correlation matrices indicate that all infrastructure sectors are highly correlated (Appendix 3). All infrastructure sectors are more correlated with Stocks than Real Estate, and are close to zero correlated with Bonds. During the stable market conditions before the global financial crisis, all sectors had a lower correlation compared with both the global financial Crisis period and the post global financial crisis period. High correlation among listed infrastructure sectors indicate that it is not optimal to construct a portfolio based solely on listed infrastructure, but the variety in performance does not support the claim of listed infrastructure constituting an own asset class. Why correlation is high for listed infrastructure is not a question addressed in this paper, but in Hall et al. (2014) the authors argue that infrastructure sectors are highly correlated due to the common effect on demand given by population and economic growth. Low correlation between listed infrastructure sectors and global bonds, indicate a potential diversification benefit with listed infrastructure and global bonds in a portfolio.

5.1.2. Market performance

Infrastructure performance among the three different contingents North America, Europe, and Asia-Pacific, for the overall period has outperformed both Stocks and Real Estate. The difference in market performance during the overall period gives an indication of that it might be a better alternative to be exposed to infrastructure in a single market and not on a global level. As Table 7 shows, North American infrastructure has a higher rate of return and a lower volatility than the two other markets.

Table 5: Infrastructure performance after continents

2003 - 2016	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Dow Jones Europe	9.22	17.63	0.45	3
Dow Jones North America	11.02	16.35	0.60	2
Dow Jones Asia Pacific	9.70	20.01	0.42	4
MSCI World Equity	6.73	17.10	0.32	6
Barclays Global Bond	4.28	4.41	0.70	1
MSCI Word Real Estate	8.30	20.17	0.35	5

Before the Global Finincial Crisis

In this pre-crisis period defined as a period of financial stability, all equity indices had a high rate of return and low volatility, resulting in Sharpe ratios above 1. All infrastructure markets outperformed Stocks in terms of risk-treturn trade-off . With a Sharpe ratio of 2.05, the European infrastructure was the best performing market. In terms of average annual return and annualized volatility, the infrastructure markets had similar performance measures with the Real Estate than Stocks.

Table 6: Infrastructure performance after markets, prior GFC

2003 - 2006

	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Dow Jones Europe	26.15	11.52	2.05	1
Dow Jones North America	18.61	10.80	1.49	3
Dow Jones Asia Pacific	23.17	15.03	1.37	4
MSCI World Equity	15.38	11.42	1.12	5
Barclays Global Bond	4.54	4.46	0.44	6
MSCI Word Real Estate	26.86	12.45	1.95	2

During the Global Financial Crisis

Compared with the previous subsample, the global financial crisis subsample indicate that all assets were negatively affected by the macroeconomic turmoil caused by the global financial crisis. Among the three infrastructure markets, the infrastructure market in Europe was that market most negativelly affected by the market turbulence. The poor performance of the European infrastructure during the financial crisis is consistent with the findings in Oyedele et al (2013) were they examine the role of European listed infrastructure in a mixed asset portfolio. One interesting remark is that both the North Ameican and Asian-Pacific infrastructure markets had a positive average annual return during the financial crisis. The decreased average annual return and increased annualized volatility is also consistent with the performance analysis based on infrastructure sectors. Once again, we argue that listed infrastructure is highly affected by short term events in the market and follow the market trend as Stocks and Real Estate

Table 7: Infrastructure performance after markets, during GFC

2007 - 2009

	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Dow Jones Europe	-0.42	26.68	-0.09	4
Dow Jones North America	2.33	25.21	0.01	2
Dow Jones Asia Pacific	1.73	32.79	-0.01	3
MSCI World Equity	-3.25	26.19	-0.20	5
Barclays Global Bond	6.54	5.12	0.89	1
MSCI Word Real Estate	-10.02	34.07	-0.35	6

After the Global Financial Crisis

The performance among the three infrastructure markets have changed in terms of risk and return compared with prior subsamples. Table X indicate a much lower return and a volatility almost at the same level for the infrastructure market, leading to a lower Sharpe ratio. After the global financial crisis the Sharpe ratio for the North American market is almost twice the size of the Asia-Pacific, and more than three times the size of the European.

Table 8: Infrastructure performance after markets, post GFC

2010 - 2016	Average annual return (%)	Annualized volatility (%)	Sharpe ratio	Sharpe index
Dow Jones Europe	3.68	15.47	0.23	6
Dow Jones North America	10.41	14.03	0.73	2
Dow Jones Asia Pacific	5.41	14.53	0.37	4
MSCI World Equity	6.06	14.74	0.40	3
Barclays Global Bond	3.17	4.04	0.76	1
MSCI Word Real Estate	5.54	15.01	0.36	5

Based on this market performance analysis we argue that the role of listed infrastructure in a mixed asset portfolio would be more of a "return amplifier" than a "risk reducer". Another argument regarding the performance of listed infrastructure is that it follows the same market trends in bear-markets as Stocks and Real Estate.

Cross-market correlation

The cross-market correlation matrices show high correlation between the different listed infrastructure markets, and high correlation between listed infrastructure markets and global stocks and global real estate (Appendix 4). These results are consistent with the cross-sector correlation. The subsample market-correlation also show the same development over time as the sector-correlation. The same low correlation between listed infrastructure sectors and global bonds apply in the cross-market correlation analysis, confirming the potential diversification benefits with listed infrastructure and global bonds in a mixed asset portfolio.

5.2. Mean-Variance Portfolio Optimization

5.2.1. Sector optimization

Figure 2 depicts the efficient frontier of two different investment opportunity sets. The blue line depicts the efficient frontier when the opportunity set only includes Stocks, Bonds and Real Estate. The red line depicts the efficient frontier after we expand the opportunity set by including listed infrastructure. When listed infrastructure is included in the base portfolio an outward shift of the efficient frontier indicate mean-variance improvements. However, the inclusion of infrastructure indicates a better risk-return trade-off when the standard deviations of the portfolios are increasing. Out of the seven infrastructure sectors available, only communication and airports are a part of the optimized portfolios. This is based on the fact that airports and communication are the sectors with the best overall risk-return trade-off.

Figure 2: Efficient frontier for infrastructure sectors January 2003 – December 2016

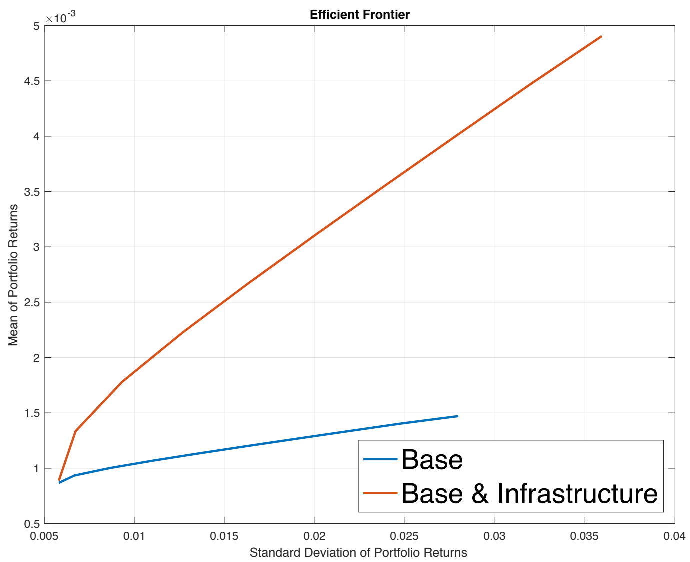


Table 9 presents the average annual return, annualized volatility, M^2 and Sharpe ratio before listed infrastructure is included in the opportunity set, while table 10 presents the same performance measures after the inclusion of listed infrastructure. By including listed infrastructure in the base portfolio, an investor is able to increase his Sharpe ratio from 0.818 to 1.266. Both the Sharpe ratio and

M^2 performance measure indicate that by including listed infrastructure in the opportunity set an investor can improve the performance of the portfolios. Comparing the different portfolios with and without infrastructure, an improvement regarding the Sharpe ratios and M^2 measures stems from an increase in the returns and not from decrease in the portfolios annualized volatility. These results are consistent with previous results from the performance analysis, where listed infrastructure exhibits higher returns, but also higher volatility than traditional Stocks.

Table 9: Mean-variance portfolios – traditional assets

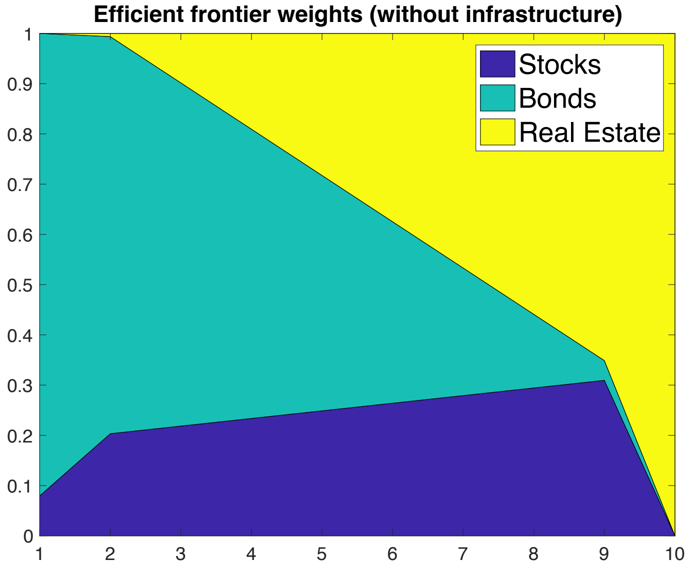
Mean-variance portfolio without infrastructure					
Portfolios	Annualized return(%)	Annualized volatility(%)	Sharpe ratio	M^2 (%)	Sharpe index
1	4.613	4.169	0.818	8.121	1
2	4.978	4.797	0.787	7.586	2
3	5.344	6.211	0.666	5.506	3
4	5.712	7.943	0.567	3.793	4
5	6.081	9.825	0.496	2.562	5
6	6.451	11.786	0.445	1.677	6
7	6.822	13.791	0.407	1.023	7
8	7.194	15.825	0.378	0.525	8
9	7.568	17.877	0.356	0.135	9
10	7.943	20.169	0.334	-0.243	10

Table 10: Mean-variance portfolio – traditional assets and infrastructure sectors

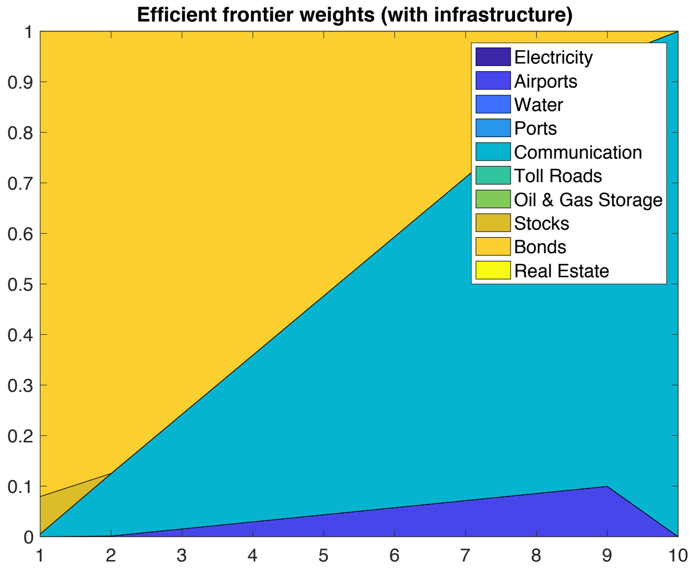
Mean-variance portfolio with infrastructure					
Portfolios	Annualized return(%)	Annualized volatility(%)	Sharpe ratio	M^2 (%)	Sharpe index
1	4.723	4.167	0.844	8.583	10
2	7.179	4.836	1.235	15.349	2
3	9.692	6.702	1.266	15.883	1
4	12.262	9.127	1.211	14.935	3
5	14.891	11.770	1.163	14.093	4
6	17.581	14.513	1.128	13.498	5
7	20.332	17.308	1.105	13.096	6
8	23.147	20.133	1.090	12.831	7
9	26.026	22.978	1.080	12.664	8
10	28.971	25.914	1.071	12.513	9

Figure 3[8]: Historical efficient frontier asset allocation

Panel A - Traditional assets



Panel B - Traditional assets and Infrastructure sectors

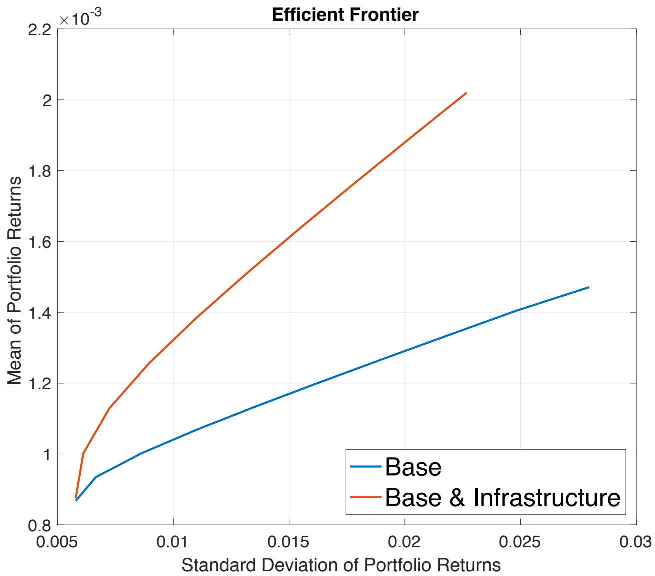


[8] Y-aksis represents the weekly return for each portfolio. X-aksis represents each portfolio. The precentage asset distribution for each portfolio is presented in Appendix 7.

5.2.2. Market optimization

Figure 4 show the results for the mean-variance portfolio optimization with and without the inclusion of listed infrastructure based on different markets. The opportunity set is expanded by including North American, European and Asian Pacific listed infrastructure. In blue, we have the base portfolio and in red we have the base portfolio including listed infrastructure. The results are consistent with the sector analysis, showing an upward shift in the efficient frontier after the inclusion of listed infrastructure in the base portfolio.

Figure 4: Efficient frontier for infrastructure markets January 2003 – December 2016



Due to the fact that North American infrastructure provides a higher return and a lower volatility compared with the other infrastructure markets, it is the only infrastructure market that is included in the optimal portfolios, as Figure 5 illustrates. Table 11 shows the potential enhancement by investing in a specific infrastructure markets. An increased Sharpe ratio and an improved M^2 measure show the potential benefits by including infrastructure in a portfolio. By expanding the opportunity set by adding North American infrastructure an investor is now able to construct a varied range of portfolios and still obtain a lower volatility and a higher return compared with the base portfolios.

In addition to the improved mean-variance trade-off, the mean-variance portfolio optimization has shown that an optimal portfolio is not constructed by including many different infrastructure sectors or markets in the same portfolio. At most, two infrastructure sectors have been in the same optimized portfolio.

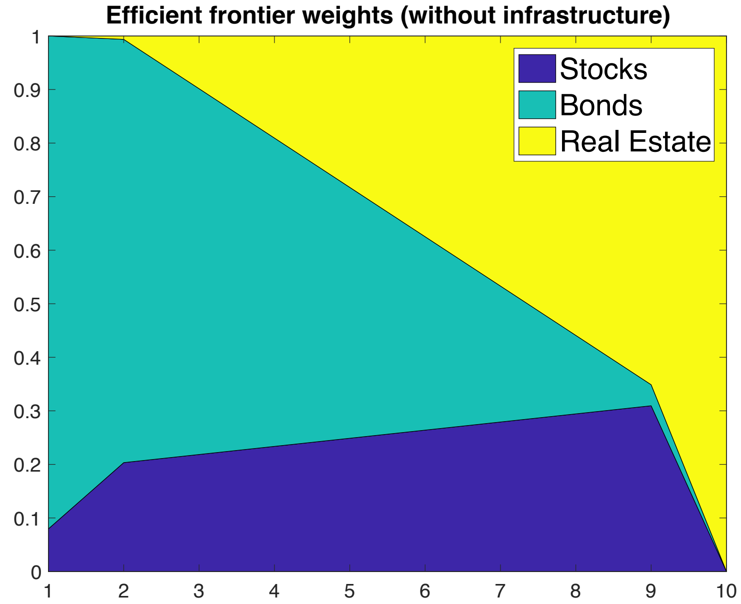
Table 11: Mean-variance portfolio – traditional assets and infrastructure markets

Mean-variance portfolio with infrastructure

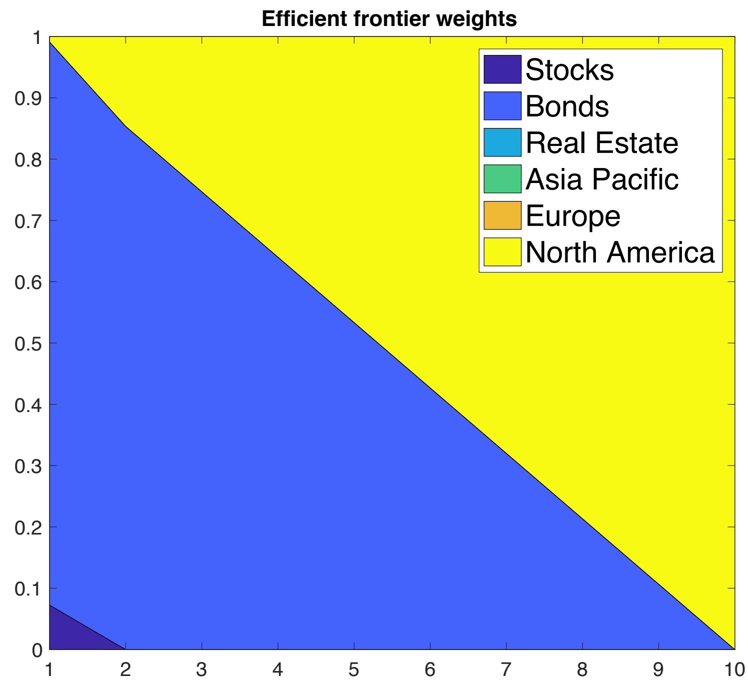
Portfolios	Annualized return(%)	Annualized volatility(%)	Sharpe ratio	M^2 (%)	Sharpe index
1	4.651	4.168	0.827	8.280	4
2	5.345	4.406	0.940	10.233	1
3	6.044	5.220	0.927	10.015	2
4	6.747	6.457	0.858	8.826	3
5	7.455	7.922	0.789	7.626	5
6	8.167	9.510	0.732	6.643	6
7	8.884	11.168	0.688	5.873	7
8	9.606	12.870	0.653	5.270	8
9	10.333	14.600	0.625	4.793	9
10	11.064	16.349	0.603	4.409	10

Figure 5[9]: Historical efficient frontier asset allocation

Panel A - Traditional assets



Panel B – Traditional assets and infrastructure markets



[9] Y-aksis represents the weekly return for each portfolio. X-aksis represents each portfolio. The precentage asset distribution for each portfolio is presented in Appendix 8.

5.3. Mean-Conditional Value at Risk

5.3.1. Sector optimization

The efficient frontiers for Mean-Variance and Mean-Conditional Value at Risk are close to identical for the higher level of the frontiers, with a minor difference on the lower lever of the frontier (Figure 6). Relatively close graphs of Mean-Variance and Mean-Conditional Value at Risk portfolios indicate that a Mean-Variance portfolio is "near optimal" in the Mean-Variance sense, and visa versa. As Figure 7 illustrates, both optimization techniques have similar weightings with bonds and communication as their primarily assets on the efficient frontier. The two techniques only differ in the sense that mean-variance optimization includes a small portion of airports at the higher level of the frontiers where the portfolios are more risky. The minor differences in the weight distributions are caused by the tail-risk for the infrastructure indices used. Despite the minor differences in weightings, we conclude that the Mean-Conditional Value at Risk optimization confirms our Mean-Variance results.

Figure 6: Historical Mean-variance and CVaR efficient frontier January 2003 – December 2016

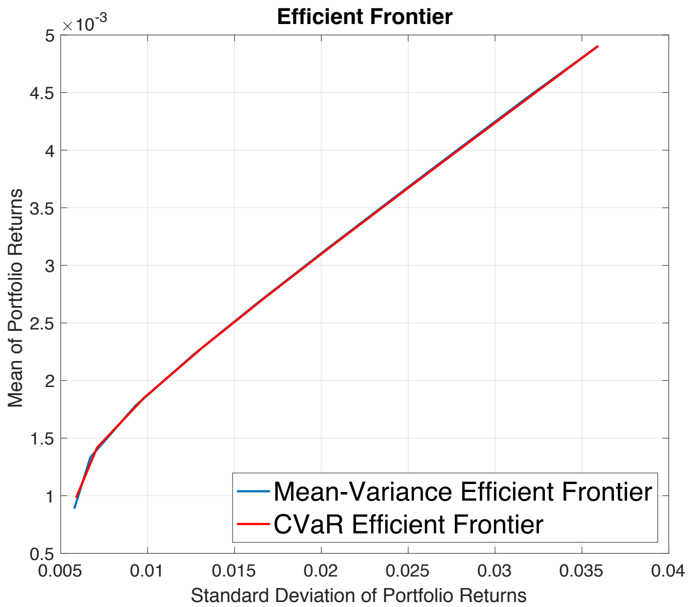
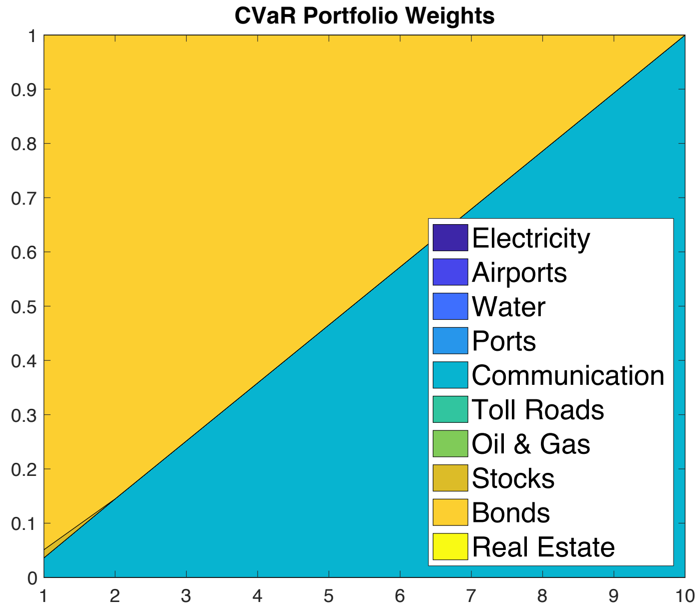
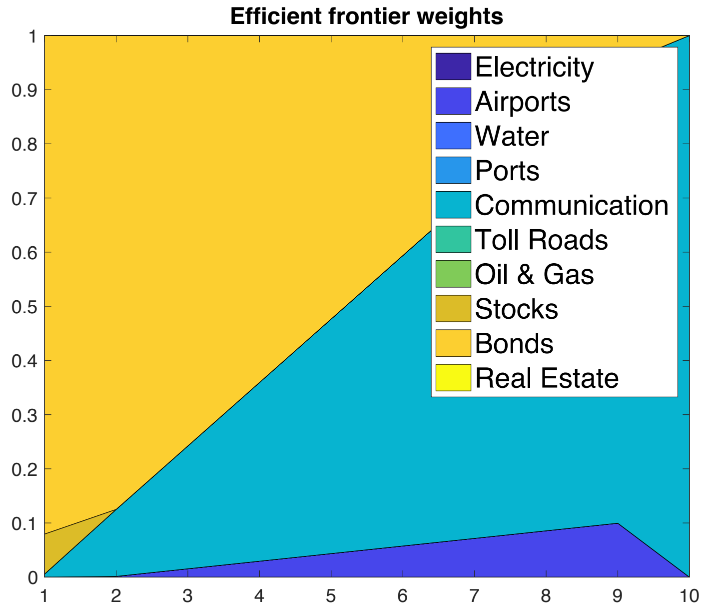


Figure 7[10]: Historical efficient frontier asset allocation for infrastructure sectors

Panel A – Conditional Value at Risk asset allocation



Panel B – Mean-variance asset allocation



[10] Y-aksis represents the weekly return for each portfolio. X-aksis represents each portfolio. The precentage asset distribution for each portfolio is presented in Appendix 7 (Mean-variance) and Appendix 9 (CVaR)

5.3.2. Market optimization

In the Mean-Variance analysis, North American infrastructure dominated both European and Asian Pacific infrastructure. The same goes for the Mean-Conditional Value at Risk optimization for the market analysis. Figure 8 depicts the efficient frontier for the Mean-Variance and the Mean-Conditional Value at Risk optimization respectively. Both techniques provide efficient frontiers that are close to identical, which again confirm that the mean-variance portfolios are “optimal”.

Comparing the asset allocation between the two techniques, both techniques also provide portfolio weights with roughly the same asset allocation. Although the differences are small, the findings demonstrate that by optimize the portfolios with a Mean-Conditional Value at Risk approach the weight distribution will be slightly lower towards Infrastructure and a bit higher towards Bonds. The difference may be explained by the difference in tail-risk between the two assets, where Bonds have lower kurtosis and less skewed returns compared to Infrastructure.

Another interesting feature is the characteristic of the portfolios returns, tail-risk (CVaR), and standard deviation when infrastructure is included and compared with the base portfolio (Appendix 6). All portfolios with infrastructure provide higher returns, lower tail-risk (CVaR), and lower standard deviation (Appendix 10).

Figure 8: Historical Mean-variance and CVaR efficient frontier January 2003 – December 2016

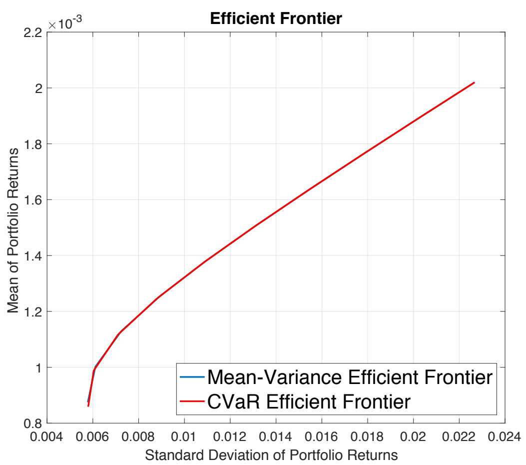
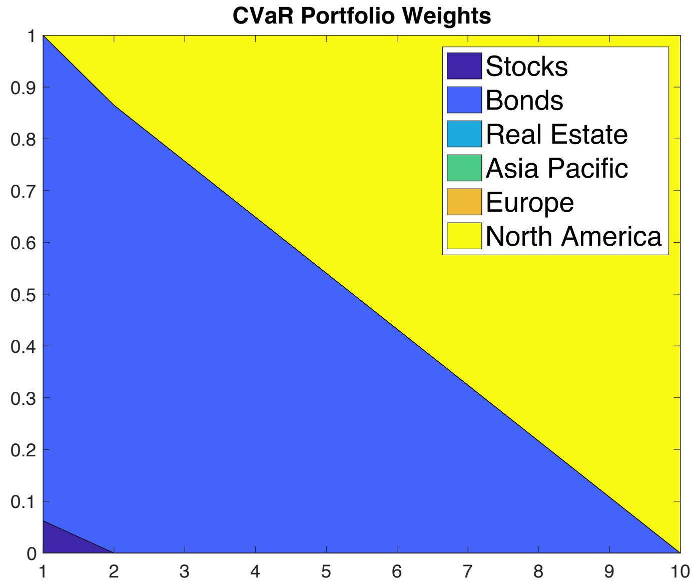
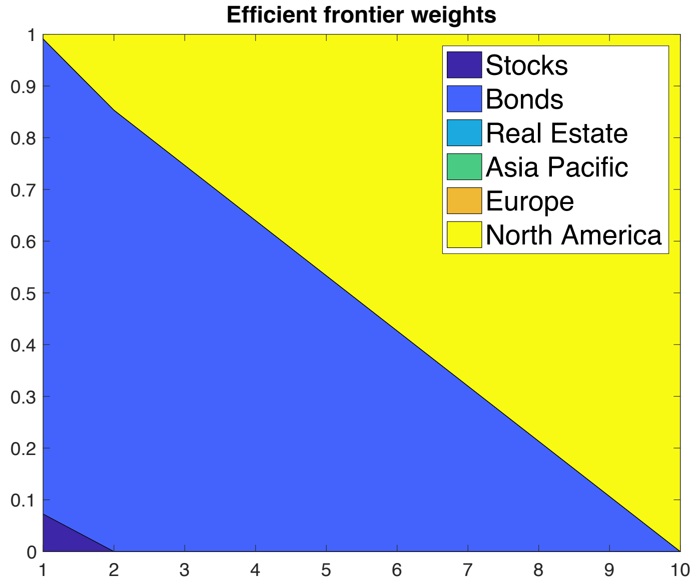


Figure 9[11]: Historical efficient frontier asset allocation for infrastructure sectors

Panel A - Conditional Value at Risk asset allocation



Panel B: Mean-variance asset allocation



[11] Y-aksis represents the weekly return for each portfolio. X-aksis represents each portfolio. The precentage asset distribution for each portfolio is presented in Appendix 8 (Mean-variance) and Appendix 10 (CVaR)

5.4. Mean-Variance Spanning Test

Including infrastructure sectors (Opportunity A)

We started with opportunity A, inclusion of listed infrastructure by sectors. Then we run the same test based on different markets (opportunity B).

Table 12: Spanning Test infrastructure sectors

Spanning test with infrastructure sectors			
	Coefficient	t-Stat	P-Value
Electricity	0.0006	0.7929	0.4281
Airports	0.0015	1.5343	0.1254
Water	0.0011	1.1640	0.2448
Ports	0.0005	0.3785	0.7052
Communication	0.0043	3.2981	0.0010
Toll Roads	0.0003	0.3120	0.7551
Oil & Gas	0.0011	1.3812	0.1676

Table 12 presents spanning test results for the infrastructure sectors. The only statistically significant improvement on the mean-variance relationship in the base portfolio is given by inclusion of communication. The same sector has also the highest alpha coefficient of 0.0043. No other listed infrastructure sector had a significant improvement on the mean-variance relationship for the base portfolio. This might suggest that improvement of a mean-variance relationship for a given base portfolio by including of listed infrastructure is highly dependent on the type of infrastructure that is being included.

Including infrastructure markets (Opportunity B)

Next, we run a spanning test on the different listed infrastructure markets. Table 13 presents the results from the markets spanning test. Although the alpha coefficient is much higher for the North American markets, suggesting that mean-variance improvement is dependent on what listed infrastructure market you include in the base portfolio, none of the variables in the markets spanning test is statistically significant.

Table 13: Spanning Test infrastructure markets

Spanning test with infrastructure markets			
	Coefficient	t-Stat	P-Value
Europe	0.0003	0.3870	0.6989
North America	0.0012	1.4410	0.1500
Asia Pacific	0.0004	0.4483	0.6540

6.0. Conclusion

In this paper, we have examined listed infrastructure investments as a means for improving the mean-variance trade-off in a mixed asset portfolio. We have used weekly data spanning from 2003 – 2016 obtained from Bloomberg. The fourteen-year timeframe was further divided into three subsamples, capturing different macroeconomic conditions. Motivation behind the research stems from the increased interest in private infrastructure investments and the increase in publicly traded infrastructure funds and dedicated infrastructure indices.

The results from the performance analysis indicate that while the historical performance vary both in terms of different sectors and different markets, the impact of a macroeconomic downturn had a negative effect regardless of how listed infrastructure was divided. Most listed infrastructure indices outperformed the world equity index and the world real estate index in the overall sample, but the results are not consistent when we divide the sample into periodic subsamples. The results indicate *that listed infrastructure should not be treated as a homogenous asset* with similar risk- and return characteristics among sectors. The correlation matrices show that the correlation between listed infrastructure and the world equity index is higher in the post-GFC sample than in the pre-GFC sample. The same analysis also shows a decline in correlation between listed infrastructure and the global bonds index from the pre-GFC sample to the post-GFC sample. The results are consistent for both the sector and the markets data sample. Based solely on correlation, we argue that there might be *diversification benefits by holding a portfolio consisting of listed infrastructure and global bonds*. The Markowitz mean-variance optimization results indicate that an optimal portfolio of bonds and listed infrastructure outperforms an optimal portfolio of bonds and traditional stocks, but the mean-variance spanning test rejects any claims of a statistically significant shift in efficient frontier of the base portfolio after the investment opportunity set includes listed infrastructure. In the sector spanning test only one out of seven sectors gave a statistically significant shift on the base portfolio´s efficient frontier. For the markets spanning test, none of the regression intercepts were statistically significant, while for the subsample spanning test with North American listed infrastructure only the pre-GFC subsample gave a statistically significant intercept. We conclude that *listed infrastructure does not* *improve the mean-variance of a mixed asset portfolio.* Research prior to this paper has not produced unambiguous results regarding the diversification benefits of listed infrastructure. While Peng and Newell (2007) and Oyedele (2013) finds evidence supporting a diversification benefit, studies such as Idzorek and Armstrong (2009) and Martin (2010) does not support this claim. Thus, as a concluding remark we suggest further research on the topic of listed infrastructure. We also suggest that future research on listed infrastructure should include a market analysis based on different sectors to examine sector similarities across different markets.

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Appendix

Appendix 1: Market Capital for each continent and infrastructure sector.

	Companies	Market Capital	Weight
North America	48	$ 568,845,903,944.07	59.55%
Europe	27	$ 229,916,126,216.53	24.07%
Asia-Pacific	26	$ 156,553,461,404.65	16.39%
Total	101	$ 955,315,491,565.24	100.00%

	Oil&Gas	Transportation	Utilities	Communication	Other infrastructure
North America	247,92	12,08	218,17	0	89,68
Europe	26,58	77,07	90,82	22,32	13,13
Asia-Pacific	0	69,88	80,7	0	5,97

*Numbers in billions

	Companies	Market Capital	Weight
Airports	11	$ 75,296,167,743.38	8.15%
Communication	8	$ 111,217,000,392.96	12.04%
Electricity	14	$ 194,180,644,601.99	21.03%
Oil&Gas	38	$ 406,425,920,992.25	44.01%
Ports	3	$ 11,733,610,184.26	1.27%
Toll Roads	10	$ 72,008,267,400.40	7.80%
Water	10	$ 52,668,166,706.09	5.70%
Total	94	$ 923,529,778,021.32	100.00%

Appendix 2 – Descriptive Statistics based on weekly observations.

Simple returns:

Base Assets			
	Stocks	Bonds	Real Estate
Mean	0,00134	0,00083	0,00147
Standard Deviation	0,02372	0,00611	0,02797
Skewness	-1,0028	-0,2215	-0,4466
Kurtosis	12,3981	3,7667	9,9105
Jarque-Bera	2808,8410	23,8528	1476,8230

Infrastructure Markets - Dow Jones Brookfield			
	North America	Europe	Asia-Pasific
Mean	0,00202	0,00160	0,00170
Standard Deviation	0,02267	0,02445	0,02775
Skewness	-0,9600	-1,3661	-1,4922
Kurtosis	14,3171	14,3840	14,7072
Jarque-Bera	4007,7870	4168,8910	4439,7610

Infrastructure Sectors - Dow Jones Brookfield							
	Airports	Communication	Electricity	Oil&Gas	Ports	Toll Roads	Water
Mean	0,00266	0,00491	0,00142	0,00181	0,00144	0,00161	0,00192
Standard Deviation	0,02857	0,03594	0,02148	0,02255	0,03933	0,02861	0,02605
Skewness	-1,0333	0,2562	-1,5722	-1,3933	-0,2371	-0,9299	-0,4923
Kurtosis	11,3510	9,2077	21,3454	15,5450	11,1557	9,0240	15,7042
Jarque-Bera	2251,11	1180,125	10537,51	5023,096	2030,027	1209,002	4938,599

Log returns:

	Stocks	Bonds	Real Estate
Mean	0,00106	0,00082	0,00107
Standard Devia	0,0240	0,0061	0,0282
Skewness	-1,4186	-0,2437	-0,8124
Kurtosis	15,4246	3,7681	10,3507
Jarque-Bera	4940,26	25,18	1723,78

Infrastructure Markets - Dow Jones Brookfield			
	North Americ	Europe	Asia-Pasific
Mean	0,00177	0,00127	0,00131
Standard Devia	0,0230	0,0249	0,0284
Skewness	-1,4436	-1,8530	-2,0714
Kurtosis	18,4152	18,8734	20,6555
Jarque-Bera	7481,37	8081,72	10003,39

Infrastructure Sectors - Dow Jones Brookfield							
	Airports	Communicatio	Electricity	Oil&Gas	Ports	Toll Roads	Water
Mean	0,00224	0,00425	0,00118	0,00155	0,00066	0,00119	0,00158
Standard Devia	0,0290	0,0358	0,0219	0,0230	0,0398	0,0290	0,0263
Skewness	-1,4956	-0,1872	-2,2514	-1,8953	-0,8832	-1,2728	-1,0840
Kurtosis	14,9986	9,4882	29,0734	20,8302	13,3281	11,1036	17,7904
Jarque-Bera	4651,11	1284,71	21294,63	10107,03	3339,42	2194,55	6796,77

Appendix 3 – Cross-sector correlation matrices

2003 - 2016

	Electricity	*Airports*	*Water*	*Ports*	*Commu-nication*	*Toll Roads*	*Oil & Gas*	*World Equity*	*Global Bonds*	*World Real Estate*
Electricity	1									
Airports	0.64	1								
Water	0.80	0.62	1							
Ports	0.50	0.68	0.56	1						
Communication	0.52	0.49	0.52	0.45	1					
Toll roads	0.68	0.77	0.65	0.65	0.48	1				
Oil & Gas	0.75	0.68	0.70	0.59	0.56	0.72	1			
World Equity	0.70	0.78	0.69	0.70	0.66	0.78	0.82	1		
Global Bonds	0.13	0.12	0.07	-0.02	-0.08	0.15	0.02	-0.09	1	
World Real Estate	0.65	0.76	0.64	0.69	0.61	0.74	0.70	0.86	0.07	1

2003 - 2006

	Electricity	*Airports*	*Water*	*Ports*	*Commu-nication*	*Toll Roads*	*Oil & Gas*	*World Equity*	*Global Bonds*	*World Real Estate*
Electricity	1									
Airports	0.50	1								
Water	0.62	0.45	1							
Ports	0.35	0.41	0.35	1						
Communication	0.25	0.22	0.21	0.18	1					
Toll roads	0.45	0.41	0.45	0.33	0.10	1				
Oil & Gas	0.67	0.52	0.52	0.38	0.31	0.62	1			
World Equity	0.52	0.54	0.45	0.37	0.53	0.41	0.69	1		
Global Bonds	0.29	0.26	0.28	0.10	-0.12	0.42	0.29	0.04	1	
World Real Estate	0.54	0.48	0.43	0.37	0.37	0.53	0.66	0.74	0.23	1

2007 - 2009

	Electricity	*Airports*	*Water*	*Ports*	*Commu-nication*	*Toll Roads*	*Oil & Gas*	*World Equity*	*Global Bonds*	*World Real Estate*
Electricity	1									
Airports	0.68	1								
Water	0.87	0.65	1							
Ports	0.61	0.79	0.66	1						
Communication	0.65	0.60	0.68	0.62	1					
Toll roads	0.78	0.86	0.75	0.80	0.64	1				
Oil & Gas	0.87	0.75	0.81	0.68	0.72	0.80	1			
World Equity	0.81	0.85	0.80	0.80	0.79	0.86	0.90	1		
Global Bonds	-0.01	0.10	-0.13	-0.07	-0.15	0.09	-0.03	-0.07	1	
World Real Estate	0.65	0.81	0.66	0.77	0.73	0.79	0.73	0.90	-0.03	1

2010 - 2016

	Electricity	*Airports*	*Water*	*Ports*	*Commu-nication*	*Toll Roads*	*Oil & Gas*	*World Equity*	*Global Bonds*	*World Real Estate*
Electricity	1									
Airports	0.65	1								
Water	0.78	0.64	1							
Ports	0.38	0.61	0.45	1						
Communication	0.62	0.61	0.58	0.38	1					
Toll roads	0.65	0.81	0.61	0.57	0.59	1				
Oil & Gas	0.64	0.65	0.63	0.55	0.63	0.66	1			
World Equity	0.62	0.79	0.63	0.67	0.65	0.80	0.78	1		
Global Bonds	0.20	0.08	0.17	-0.02	0.05	0.09	-0.04	-0.17	1	
World Real Estate	0.70	0.82	0.67	0.64	0.68	0.76	0.69	0.84	0.12	1

Appendix 4 – Cross-market correlation matrices

2003 - 2016

	Asian Pacific infrastructure	European infrastructure	North American infrastructure	Global Stocks	Global Bonds	Global Real Estate
Asian Pacific infrastructure	1					
European infrastructure	0.675	1				
North American infrastructure	0.624	0.708	1			
Global Stocks	0.707	0.779	0.827	1		
Global Bonds	0.115	0.147	-0.027	-0.085	1	
Global Real Estate	0.735	0.700	0.731	0.855	0.070	1

2003 - 2006

	Asian Pacific infrastructure	European infrastructure	North American infrastructure	Global Stocks	Global Bonds	Global Real Estate
Asian Pacific infrastructure	1					
European infrastructure	0.473	1				
North American infrastructure	0.396	0.554	1			
Global Stocks	0.365	0.554	0.727	1		
Global Bonds	0.351	0.392	0.133	0.038	1	
Global Real Estate	0.511	0.568	0.660	0.743	0.229	1

2007 - 2009

	Asian Pacific infrastructure	European infrastructure	North American infrastructure	Global Stocks	Global Bonds	Global Real Estate
Asian Pacific infrastructure	1					
European infrastructure	0.778	1				
North American infrastructure	0.698	0.787	1			
Global Stocks	0.800	0.857	0.903	1		
Global Bonds	0.039	0.040	-0.129	-0.066	1	
Global Real Estate	0.766	0.724	0.759	0.900	-0.027	1

2010 - 2016	Asian Pacific infrastructure	European infrastructure	North American infrastructure	Global Stocks	Global Bonds	Global Real Estate
Asian Pacific infrastructure	1					
European infrastructure	0.605	1				
North American infrastructure	0.608	0.655	1			
Global Stocks	0.718	0.752	0.758	1		
Global Bonds	0.072	0.145	-0.005	-0.167	1	
Global Real Estate	0.778	0.719	0.720	0.836	0.124	1

Appendix 5 – Mean Variance portfolio weights, weekly return, and standard deviation – traditional assets

Mean-Variance - Base portfolio

		Weights		
Weekly Portfolio Return (%)	Weekly Portfolio Std (%)	Equity	Bonds	Real Estate
0,0868	0,5781	0,0796	0,9204	0,0000
0,0935	0,6652	0,2033	0,7904	0,0063
0,1002	0,8614	0,2185	0,6831	0,0984
0,1069	1,1015	0,2337	0,5758	0,1905
0,1136	1,3625	0,2488	0,4685	0,2827
0,1203	1,6344	0,2640	0,3612	0,3748
0,1270	1,9125	0,2792	0,2539	0,4669
0,1337	2,1946	0,2944	0,1466	0,5591
0,1404	2,4792	0,3095	0,0393	0,6512
0,1471	2,7969	0,0000	0,0000	1,0000

Appendix 6 – Mean-Conditional Value at Risk portfolio weights, weekly return, and standard deviation – traditional assets

Mean-conditional Value at Risk - Base portfolio

Weekly Portfolio Return (%)	95CVaR (%)	Weekly Portfolio Std (%)	Weights: Equity	Bonds	Real Estate
0,0859	1,2796	0,5797	0,0796	0,9204	0,0000
0,0927	1,4679	0,6472	0,2033	0,7904	0,0063
0,0995	1,9867	0,8399	0,2185	0,6831	0,0984
0,1063	2,5881	1,0795	0,2337	0,5758	0,1905
0,1131	3,2507	1,3435	0,2488	0,4685	0,2827
0,1199	3,9440	1,6187	0,2640	0,3612	0,3748
0,1267	4,6592	1,9007	0,2792	0,2539	0,4669
0,1335	5,3818	2,1868	0,2944	0,1466	0,5591
0,1403	6,1138	2,4796	0,3095	0,0393	0,6512
0,1471	6,8794	2,7969	0,0000	0,0000	1,0000

Appendix 7 – Mean-variance portfolio weights, weekly return, and standard deviation with traditional assets and infrastructure sectors

Mean-variance - Base and Infrastructure sectors

Weekly Portfolio Return (%)	Weekly Portfolio Std (%)	Weights: Electricity	Aiports	Water	Ports	Communication	Toll Roads	Oil&Gas	Stocks	Bonds	Real Estate
0,0888 %	0,5779 %	0,0000	0,0000	0,0000	0,0000	0,0057	0,0000	0,0000	0,0739	0,9205	0,0000
0,1334 %	0,6706 %	0,0000	0,0014	0,0000	0,0000	0,1237	0,0000	0,0000	0,0000	0,8749	0,0000
0,1781 %	0,9294 %	0,0000	0,0155	0,0000	0,0000	0,2268	0,0000	0,0000	0,0000	0,7577	0,0000
0,2227 %	1,2657 %	0,0000	0,0295	0,0000	0,0000	0,3300	0,0000	0,0000	0,0000	0,6405	0,0000
0,2673 %	1,6323 %	0,0000	0,0435	0,0000	0,0000	0,4331	0,0000	0,0000	0,0000	0,5234	0,0000
0,3119 %	2,0126 %	0,0000	0,0575	0,0000	0,0000	0,5363	0,0000	0,0000	0,0000	0,4062	0,0000
0,3566 %	2,4002 %	0,0000	0,0716	0,0000	0,0000	0,6394	0,0000	0,0000	0,0000	0,2890	0,0000
0,4012 %	2,7920 %	0,0000	0,0856	0,0000	0,0000	0,7426	0,0000	0,0000	0,0000	0,1719	0,0000
0,4458 %	3,1865 %	0,0000	0,0996	0,0000	0,0000	0,8457	0,0000	0,0000	0,0000	0,0547	0,0000
0,4905 %	3,5936 %	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Appendix 8 – Mean-variance Portfolio weights, weekly return, and standard deviation with traditional assets and infrastructure markets

Mean-variance - Base & All Infrastructure markets

Weekly Portfolio Return (%)	Weekly Portfolio Std (%)	Weights: Equity	Bonds	Real Estate	Asia Pacific	Europe	North America
0,0875 %	0,5780 %	0,0725	0,9186	0,0000	0,0000	0,0000	0,0088
0,1002 %	0,6110 %	0,0000	0,8535	0,0000	0,0000	0,0000	0,1465
0,1129 %	0,7238 %	0,0000	0,7468	0,0000	0,0000	0,0000	0,2532
0,1256 %	0,8954 %	0,0000	0,6402	0,0000	0,0000	0,0000	0,3598
0,1384 %	1,0986 %	0,0000	0,5335	0,0000	0,0000	0,0000	0,4665
0,1511 %	1,3187 %	0,0000	0,4268	0,0000	0,0000	0,0000	0,5732
0,1638 %	1,5487 %	0,0000	0,3201	0,0000	0,0000	0,0000	0,6799
0,1765 %	1,7847 %	0,0000	0,2134	0,0000	0,0000	0,0000	0,7866
0,1893 %	2,0247 %	0,0000	0,1067	0,0000	0,0000	0,0000	0,8933
0,2020 %	2,2673 %	0,0000	0,0000	0,0000	0,0000	0,0000	1,0000

Appendix 9 – Mean-Conditional Value at Risk portfolio weights, weekly returns, and standard deviation with traditional assets and infrastructure sectors

Mean-Conditional Value at risk - Base and infrastructure sectors

			Weights									
Weekly Portfolio Return (%)	95CVaR (%)	Weekly Portfolio Std (%)	Electricity	Aiports	Water	Ports	Communication	Toll Roads	Oil&Gas	Stocks	Bonds	Real Estate
0,0982 %	1,2617 %	0,5880 %	0,0000	0,0000	0,0000	0,0000	0,0360	0,0000	0,0000	0,0150	0,9490	0,0000
0,1418 %	1,4720 %	0,7089 %	0,0000	0,0000	0,0000	0,0000	0,1448	0,0000	0,0000	0,0000	0,8552	0,0000
0,1853 %	1,9582 %	0,9820 %	0,0000	0,0000	0,0000	0,0000	0,2517	0,0000	0,0000	0,0000	0,7483	0,0000
0,2289 %	2,6343 %	1,3181 %	0,0000	0,0000	0,0000	0,0000	0,3586	0,0000	0,0000	0,0000	0,6414	0,0000
0,2725 %	3,4129 %	1,6798 %	0,0000	0,0000	0,0000	0,0000	0,4655	0,0000	0,0000	0,0000	0,5345	0,0000
0,3161 %	4,2154 %	2,0537 %	0,0000	0,0000	0,0000	0,0000	0,5724	0,0000	0,0000	0,0000	0,4276	0,0000
0,3597 %	5,0507 %	2,4341 %	0,0000	0,0000	0,0000	0,0000	0,6793	0,0000	0,0000	0,0000	0,3207	0,0000
0,4033 %	5,8932 %	2,8184 %	0,0000	0,0000	0,0000	0,0000	0,7862	0,0000	0,0000	0,0000	0,2138	0,0000
0,4469 %	6,7378 %	3,2052 %	0,0000	0,0000	0,0000	0,0000	0,8931	0,0000	0,0000	0,0000	0,1069	0,0000
0,4905 %	7,5839 %	3,5936 %	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Appendix 10 – Mean-Conditional Value at Risk portfolio weights, weekly returns, and standard deviation with traditional assets and infrastructure markets

Mean-Conditional Value at Risk - Base & All Infrastructure markets portfolio

			Weights					
Weekly Portfolio Return (%)	95CVaR (%)	Weekly Portfolio Std (%)	Equity	Bonds	Real Estate	Asia Pacific	Europe	North America
0,0859 %	1,2796 %	0,5797 %	0,0623	0,9377	0,0000	0,0000	0,0000	0,0000
0,0988 %	1,3787 %	0,6038 %	0,0000	0,8652	0,0000	0,0000	0,0000	0,1348
0,1117 %	1,6081 %	0,7099 %	0,0000	0,7571	0,0000	0,0000	0,0000	0,2429
0,1246 %	1,9785 %	0,8798 %	0,0000	0,6489	0,0000	0,0000	0,0000	0,3511
0,1375 %	2,4367 %	1,0840 %	0,0000	0,5408	0,0000	0,0000	0,0000	0,4592
0,1504 %	2,9551 %	1,3064 %	0,0000	0,4326	0,0000	0,0000	0,0000	0,5674
0,1633 %	3,5106 %	1,5391 %	0,0000	0,3245	0,0000	0,0000	0,0000	0,6755
0,1762 %	4,0877 %	1,7782 %	0,0000	0,2163	0,0000	0,0000	0,0000	0,7837
0,1891 %	4,6756 %	2,0214 %	0,0000	0,1082	0,0000	0,0000	0,0000	0,8918
0,2020 %	5,2675 %	2,2673 %	0,0000	0,0000	0,0000	0,0000	0,0000	1,0000