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Doctoral Thesis

Infrastructure as a Financial Asset Class

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Declaration of Authorship

I, Athina Panayiotou, declare that this thesis entitled, 'Infrastructure as a Financial Asset Class' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: ____

Date: ____

"You and I come by road or rail, but economists travel on infrastructure"

Margaret Thacher, *Speech to Conservative Women's Conference,1985*

Abstract

One of the greatest challenges of 21^{st} century is how to address the infrastructure needs which are fast arising around the world. More and better quality infrastructure is demanded in new economies such as China and India, while in mature economies such as Europe and the United States, ageing infrastructure calls for immediate repair and replacement. Even though governments understand the importance of infrastructure as a catalyst of growth, they can no longer sustain these investments alone. As a result, we can clearly observe the presence of a continuous infrastructure investment gap. In response, governments worldwide are turning to private investors in order to sustainably bridge this widening gap. However, private investors remain cautious in relation to this young asset class, as there is still limited information about the financial performance of infrastructure.

The goal of this thesis is to study, for the first time in detail, infrastructure as a new financial asset. This analysis is among the few to examine the investment characteristics of different infrastructure sectors and sub-sectors, and is the first to study the significance of this differentiation at the portfolio level. Using different optimisation techniques, this thesis seeks to evaluate whether private investors should focus on a single infrastructure sector, or instead are better off investing in a portfolio containing multiple infrastructure sectors.

Lastly, the study aims to prove evidentially the best way to access infrastructure by comparing the listed and the much opaque unlisted infrastructure space. The results of this thesis show that infrastructure consists of different heterogeneous infrastructure sectors thus, by focusing on a single listed infrastructure sector, fund managers will be able to gain complete knowledge of the performance of the sector and still enjoy diversification benefits. Moreover, results indicate that, despite the attractive performance of unlisted infrastructure, public policy is a key lever in attracting private investments into infrastructure.

JOURNAL PUBLICATIONS

- Panayiotou, A. and Medda, F. (2016). Portfolio of Infrastructure Investments: Analysis of European Infrastructure, *Journal of Infrastructure Systems* , p.04016011.
- Panayiotou, A. and Medda, F. (2014), Attracting Private Sector Participation in Transport Investment, *Procedia-Social and Behaviour Science*, 111(5), pp. 424-431.
- Panayiotou, A. and Medda, F. (2014), Attracting Private Sector Participation in Infrastructure Investment: The UK case. *Public Money and Management Journal*, 34(6), pp. 425-431.

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- Panayiotou, A. and Medda, F. (2017). Portfolio of infrastructure Investments: A Comparison between a Listed and an Unlisted Infrastructure Portfolio, *Infrastructure Conference for Pension Funds*, London, United Kingdom
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Abbreviations

CDaR	Conditional Drawdown at Risk
CVaR	Conditional Value at Risk
MAD	Mean-Absolute Deviation
MVO	Mean-Variance Optimisation
PPP	Public Private Partnerships
SD	Standard Deviation
VaR	Value at Risk

Chapter 1

Introduction

1.1 The Infrastructure Gap

By the middle of the 21^{st} century, the world population is expected to reach 9.7 billion, 66% of the world's inhabitants are projected to live in urban areas, and one in five people will be over 60 years old (United Nations, Department of Economic and Social Affairs, 2014, 2015*a*,*b*). The increasing trends of urbanisation, population growth and ageing populations are creating an entirely new set of expectations for infrastructure worldwide (PWC, 2014). As individuals, companies, economies, and societies evolve, infrastructure systems will have to adapt and progress in order to provide adequate support systems for people across the globe (KPMG, 2016). The world needs improved transportation, better water systems, more green energy, and newly developed and more integrated telecommunication systems if it is to grow and develop sustainably. For this reason, infrastructure presents one of the momentous challenges of the 21^{st} century.

Woetzel et al. (2016) estimate that, between 2016 and 2030, an annual amount of US$3.3 trillion across the world is needed to sustain future demographic and economic trends. As can be seen in Figure 1.1, a total aggregate amount of US$49.1 trillion is required globally. Figure 1.1 also sets out the amount needed in terms of worldwide aggregate spending and as a percentage of GDP among different infrastructure sectors. Similarly, the European Commission predicts that Europe will need €2 trillion of infrastructure investments annually (Inderst, 2009). Following the above data, many public institutions and new initiatives alike are continuously being set up around the world, with the sole purpose of tackling infrastructure investment needs. The development of the National Infrastructure Commission and the Green Investment Bank in the UK, the European Investment Bank (EIB) Project Bond Initiative, the Committee on Revisiting & Revitalising the PPP Model of Infrastructure Development in India, and the Asian Infrastructure Investment Bank in China represent just a few examples of governments around the world that have pledged to enhance their infrastructure investments.

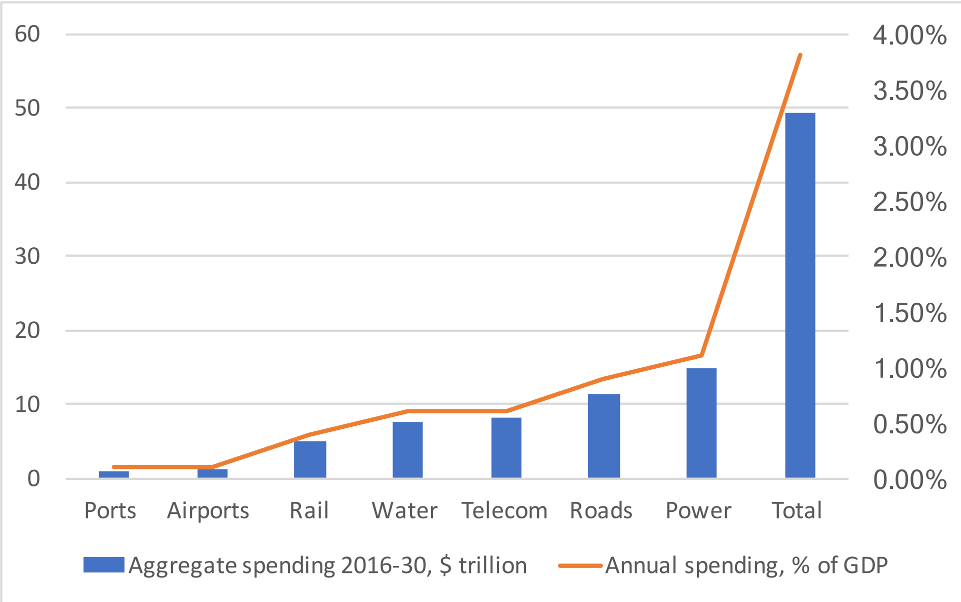


Figure 1.1: Global Infrastructure Investment needs 2016-2030, $ trillion

Source: McKinsey & Company, 2016

While infrastructure's high positioning in government agendas is evident, the extent of the budget that can be allocated to it is always contingent upon a country's economic affluence and available resources. This creates the well-known phenomenon coined as the 'infrastructure gap'. A chief example of this gap can be seen in the constrained government spending that occurred after the 2008 financial crisis. In effect, according to the International Monentary Fund (2016), government spending as a percentage of GDP in the European Union, emerging markets and developing economies in Latin America and the Caribbean, the Middle East and North America, is not expected to increase before 2020. In addition, for countries in the European Union, government spending will not even reach their pre-crisis levels by 2020. Accordingly, the aforementioned increase in infrastructure needs, driven by demographic trends and coupled with an existing asset supply that is decreasing due to ageing assets, cannot be fully achieved. Therefore, a noteworthy gap remains between required annual levels of investment and actual existing investments. Following the above logic, if government spending is not to increase, the traditional and once single financier of infrastructure can no longer support infrastructure investment needs by itself. Thus, since the infrastructure gap cannot be bridged by public finance alone, financially constrained governments are forced to turn to the private sector and particularly to institutional investors in order to fill this gap (Authers, 2015). Inevitably, the question of who can bridge the infrastructure gap now becomes, why would infrastructure be of interest to institutional investors to start with?

Institutional investors such as pension funds and insurance companies are on the hunt for long-term investments that can match their long-term liabilities. They want a good match both in relation to time and quantity between the realised value of their investments and their existing liabilities (Richard et al., 2013). This challenge has become more problematic in recent years, as the traditionally preferred asset classes for pension fund managers (sovereign and corporate bond yields) are under-performing, creating a chasm between pension fund assets and their growing liabilities (The Federal Reserve Bank of St. Louis, 2013). Even though the situation of the pension fund deficit has improved since 2013, pension fund deficits nevertheless persist (Pension Protection Fund, 2015). Always on the lookout for better alternatives, in the early 2000s infrastructure started to gain momentum as a possibly new asset class whose perceived financial benefits were becoming particularly appealing to institutional investors.

Investment in infrastructure by institutional investors can be achieved either through the listed or unlisted market, with evidence supporting both trends. According to Preqin (2016) 2015 witnessed 46 unlisted funds that reached financial closure with an all-time high average fund size of $858mn, while the listed infrastructure market had a record of 46 listed funds active in the market at the beginning of 2016.

Private investment in infrastructure is not a new phenomenon. Due to the nature and importance of infrastructure goods and services, infrastructure assets were traditionally under the authority of the governments. The rate at which infrastructure started to move away from its public ownership into the hands of private investors differs between countries. Countries such as Australia and United Kingdom (especially under the Thatcher administration) undergone infrastructure privatisations since the 1970s and continue through 1980s and 1990s (RREEF, 2015). The heterogeneous privations and regulation of the markets did not create the concept of an infrastructure asset class. Infrastructure was merely moving from public hands into private ownership. However, in the last few decades, institutional investors, who are on the look out for investments with high yields that do not move with traditional (stock and bond) markets, started to recognise infrastructure as a new emerging asset class. This is what led to the emergence of the concept of an infrastructure asset class and examining the performance of this infrastructure asset class in depth will be the focus of this thesis.

Investment in infrastructure by institutional investors can be achieved either through the listed or unlisted market, with evidence supporting both trends. According to Preqin (2016) 2015 witnessed 46 unlisted funds that reached financial closure with an all-time high average fund size of $858mn, while the listed infrastructure market had a record of 46 listed funds active in the market at the beginning of 2016.

When we consider the unlisted market, we notice that institutional investors can access and invest in infrastructure in two ways. Firstly, an investor can invest directly in an infrastructure project. Secondly, an investor can now also indirectly tap into the unlisted infrastructure market through a new vehicle known as an unlisted infrastructure fund. Similarly, moving on to the listed market, investors can also access the infrastructure space through listed infrastructure. Listed infrastructure consists of securities of publicly traded companies that either have a stake or a control in the operation of an infrastructure project or a listed infrastructure fund. Investing in the listed market offers investors a more liquid way of accessing infrastructure (CBRE, 2014). Investors can invest directly in listed infrastructure by buying stocks of listed infrastructure companies or indirectly by buying shares of listed infrastructure funds.

It is important to note that by investing in unlisted infrastructure an investor is making an investment into pure infrastructure assets and all its returns are a result of the underlying infrastructure assets' performance. On the other hand, by investing in listed infrastructure can be considered as investing in mixed infrastructure companies/funds, as while you invest in the listed infrastructure company, the company's profits can be invested in a completely different sector. Thus, the dividends of the shareholder could come from mixed sources.

Despite the growing interest of private investors in infrastructure assets, these are not yet sufficient to cover the enormous global infrastructure needs. While valuable opportunities potentially exist for private investors, the novelty of the sector presents a deficit of information and awareness around infrastructure's financial performance. This results in vast amounts of available capital money remaining locked rather than invested. Consequently, in order to close the infrastructure gap, the way we think about infrastructure will have to change. Even though infrastructure is acknowledged as a new financial asset, there still exist grey areas and lack of understanding around the financial performance of infrastructure sectors, liquidity issues, and political and regulatory risks. Extensive research and ready access to knowledge in those areas will boost investor confidence towards infrastructure projects, thereby unlocking private funding and bridging the gap between infrastructure investment needs and asset supply. To this end, the next section aims to improve our understanding of infrastructure investments.

Table 1.1: Classification of Infrastructure

Economic Infrastructure				Social Infrastructure
Energy	**Transport**	**Utilities**	**Telecom**	**National Buildings**
Fossil Fuels	Airports	Power	Networks	Schools
Solar Energy	Ports	Water	Towers	Hospitals
Wind Energy	Toll Roads	Sewage	Satellites	Prisons
Other Renewables	Bridges	Natural Gas		Stadiums
	Railways			

1.2 Defining Infrastructure as a single asset

The novelty of infrastructure investments still acts as a preventive force in naturalising infrastructure investments as a financial asset class of its own. Despite the fact that during the early 2000s infrastructure emerged as a new, independent asset class, some research studies continue to allocate infrastructure as a subset of existing financial asset classes (Leola, 2009, RREEF, 2007). In effect, a key question is whether we really can refer to infrastructure as a single asset.

For this reason, before examining infrastructure as a financial asset class, we will first take a step back and examine what actually constitutes infrastructure. There is wide research in both industry and academia that attempts to define and classify infrastructure (Della Croce, 2012). In this thesis the term infrastructure is divided into two broad categories: Economic Infrastructure and Social Infrastructure. Economic Infrastructure consists of transport, utilities, energy, and telecommunication services that can be further divided into sub-sectors, whereas Social Infrastructure refers to public assets such as hospitals, schools and prisons. This division, as well as examples of different sectors and assets that exist within them, is illustrated in Table 1.1. Deducing from this, infrastructure is certainly a vast and complex asset class.

It is worth mentioning that the classification of infrastructure differs among researchers and practitioners (World Economic Forum, 2010). Another prominent way of classifying infrastructure is by looking at the stage of development of the specific asset. Usually this classification of infrastructure divides assets into two main categories: (1) greenfield investments, which are assets that have not yet been built and thus, for the first few years do not generate revenue, and (2) brownfield investments, which refer to assets already in operation and able to generate stable cash-flows (Weber and Hans, 2010). In the middle of the two lies 'growth infrastructure', which refers to investments where the physical entity exists but the project requires either a value-added investment (such as an expansion), or an improvement to an existing project (such as a renovation) (Della Croce, 2011). Developmental classification analyses infrastructure through the risk/return profile of the assets. According to RREEF (2015), brownfield investments are said to have a low risk/return, while greenfield investments are associated with higher risks, including construction risks along with higher returns (that compensate for the added risks).

Without disregarding the diverse ways one can classify infrastructure, this thesis will retain the classification of Economic and Social infrastructure, as it is the belief of the author that heterogeneity of risks/returns between these different sectors and sub-sectors exists, even among projects in the same stage of development. Most researchers who have studied the financial performance of infrastructure have examined infrastructure as a whole, ignoring in this way the differences among infrastructure's sectors and sub-sectors. To achieve a valid, well-rounded and in-depth examination of a financial profile, an asset manager needs to identify and understand the specificities and inherent risks of each sector and sub-sector. The infancy and limited applications within this classification system acts as a deterrent for private investors who do not yet fully understand the potential financial performance of infrastructure assets.

1.3 Motivation of the thesis

As we have discussed, there is uncertainty as to where to place infrastructure within the financial sphere, which only magnifies our inability to fully understand and classify infrastructure based on its financial performance. To this end, and drawing from the fact that examining infrastructure as a single asset class within one asset is erroneous, this thesis studies infrastructure from a financial perspective and recognises it as a complex asset class. Furthermore, the primary focus of this research is on economic infrastructure, on the basis that economic infrastructure offers a vast array of investment opportunities across a wide spectrum of different sectors, as opposed to social infrastructure. In addition, economic infrastructure generates more stable income for investors through user fees or toll roads, while social infrastructure payments do not rely on either of these.

To properly scrutinise economic infrastructure, the thesis will explore three pertinent questions that aim to tackle the regulatory and financial environment surrounding infrastructure investments, examine the financial performance of different infrastructure sectors and sub-sectors, and analyse how to best construct a portfolio of infrastructure investments:

- **Why** despite the huge amounts of available capital in the market, has the infrastructure gap not yet been bridged?
- Are all infrastructure characteristics shared by all infrastructure sectors and sub-sectors? **What** are the financial differences among infrastructure sectors or sub-sectors?
- **How** should an infrastructure portfolio be constructed?

The thesis will first examine the state of play of European and UK infrastructure investment in order to verify that a still-hesitant private sector exists in regard to infrastructure investments. We will also suggest mechanisms and regulatory frameworks suitable for unlocking private finance. To formulate this, the research is built on three foundation questions related to the availability, structure, and regulations associated with infrastructure investment.

The second research question of the thesis studies the diversity within the infrastructure asset class. As Table 1.1 shows, infrastructure should not be construed as a single asset, as there is substantial diversity and heterogeneity among the infrastructure assets. However, most of the research on infrastructure has formulated the assumption that, despite its diversity, the attractive characteristics of infrastructure assets are shared among all the different sectors and sub-sectors. Nevertheless, to date there is no research to corroborate the homogeneous characteristics of infrastructure nor are there studies that give close scrutiny to, or provide thoroughgoing discussion of, specific infrastructure sectors such as Energy, Transport, Utilities, and Telecom. For instance, the extent to which infrastructure sectors are affected by macroeconomic conditions differs between sectors. By this we mean that Transport will usually fluctuate more with demand than, for example, a regulated utility sector such as Water. Therefore, in this thesis the primary research line argues that infrastructure is a vast asset class consisting of different sectors and sub-sectors, each with its own historical profile.

In so doing, we take full advantage of the second objective of the thesis, which is to be among the few researchers who investigate whether the asserted proposed characteristics of listed infrastructure are present in all of the different sectors and sub-sectors. We carry out this study at both EU and UK levels. Unfortunately, to the best of our knowledge, there are no sectoral indexes that break down unlisted infrastructure into different sectors; therefore, we conduct this examination with regard to listed infrastructure only.

Following the research line mentioned above, infrastructure assets need special attention on the specific risks and opportunities that can only be addressed at the sector and sub-sector level (Beeferman and Wain, 2013). It is therefore paramount that the private investor and asset manager have highly detailed knowledge about specific infrastructure sectors and sub-sectors. For this reason, the present thesis takes an extra step in our third research question, by examining *how* a portfolio of infrastructure investments should be constructed. Thereafter, we study for the very first time the possibility of investing in a specific sector alone while still having the ability to diversify. In this way, the asset manager will not only still be able to obtain diversification benefits, but will also gain the specialist knowledge required to assess these investments. This thesis effectively evaluates the benefits of specialising in one area versus diversifying. The speciality of knowledge of specific sectors should be to such depth that it would be preferable for the asset manager to introduce into the portfolio one sector of infrastructure, even if she or he were to compromise some diversification benefit as a result. To check our innovative approach, we test financially to confirm whether such a portfolio will still be optimal. This can be significant both for asset managers and listed infrastructure investors alike, as the transparency existing in the equity market enables investors to focus. Recognising that infrastructure is a new asset class, with small available datasets that disallow us to use traditional financial techniques, is to take a large step towards better understanding this asset class. Uncertainty about the behaviour of listed infrastructure calls for more alternative optimisation techniques, but to our knowledge this is a very underdeveloped area at the moment, and only a few scholars have made the attempt. In order to assess how an investor should invest in listed infrastructure by determining the allocation into different infrastructure sectors and sub-sectors more thoroughly, we test the construction of each listed portfolio under different measures of risk. By doing so, we gain insights into the defensiveness and downside protections of the different infrastructure sectors and sub-sectors.

Last but not least, in studying *how* a portfolio of infrastructure investments should be constructed, we observe in Chapter 2 that nearly no research is available which directly compares the listed and unlisted infrastructure markets within an institutional portfolio. Whereas the present thesis does offer a comparison as to which is the best way to access the infrastructure market for different institutional investors. To this end, we conduct an empirical examination between a portfolio that invests in the indirect infrastructure market along with its traditional portfolio, and one that invests in listed infrastructure instead. This section offers a significant contribution to the literature, given that scant available data in the opaque unlisted infrastructure funds market hinders researchers' attempts to examine the financial performance of investing indirectly in the unlisted infrastructure market, despite the fact that it is currently the most common method of accessing infrastructure.

1.4 Structure of thesis

The structure of the thesis is set out below and provides an outline for each chapter that follows.

Chapter 1 describes the context of this study, highlighting the main research areas and the objectives of the thesis.

Chapter 2 gives a comprehensive overview of the studies conducted in academia and in industry on the examination of infrastructure assets. It concentrates on work carried out specifically on the characteristics of the infrastructure market and research on the performance of infrastructure in the portfolio context, as this is an area where the thesis delves deeply analytically.

Chapter 3 gives background on the data used in this study by examining the summary statistics of the data. Moreover, this Chapter outlines the mean-variance analysis and addresses its critics. This Chapter also concentrates on the different portfolio methodologies followed in this thesis by discussing the weaknesses and strengths of each in the application of infrastructure assets.

The rest of the Chapters aim to address and target the objectives of the thesis.

Chapter 4 tackles the first research question of the objectives in a study of the UK and EU financial and regulatory drawbacks that hinder private infrastructure investment, by examining the availability and the structure of infrastructure financial mechanisms and the regulatory conditions of these investments.

Chapters 5 to 8 tackle the remainder of the thesis objectives which refer to the second and third questions of the thesis.

Chapter 5 examines the significance of listed infrastructure sectors and subsectors by assessing the investment characteristics and performance of different infrastructure indexes in Europe. The aim here is to prove evidentially whether the investor should invest in a portfolio containing different infrastructure sectors or whether it is still possible to obtain diversification benefits by investing in just one infrastructure sector.

Chapter 6 adds to Chapter 5, by examining the infrastructure portfolios developed in Chapter 5 under different risk measures, using both an in-sample and an out-of-sample analysis.

Chapter 7 repeats a similar analysis to Chapter 5 ,but focusses at country level, using United Kingdom data.

Chapter 8 demonstrates how investors should access the infrastructure market through an analysis of the benefits and risks of both the listed and unlisted infrastructure market. The Chapter also empirically investigates the performance of a portfolio when allocating into European listed infrastructure sectors compared to allocating into unlisted infrastructure funds.

Chapter 9 highlights the main conclusions drawn from the thesis chapters and gives suggestions for further research in regard to the new regulation of institutional investors, Solvency II, and its applicability to infrastructure.

Chapter 2

Infrastructure as an Asset Class

2.1 Introduction

Until recently, the literature on infrastructure has been primarily concerned with political and structural aspects that aim to assess how PPP contracts should be formed. Other authors have investigated the economic benefits of building a new road, a new power station or an offshore wind farm; but in these studies, the traditional finance literature has often been ignored, and so the financial properties of these physical entities have also remained unexplored. Infrastructure assets were in large part publicly owned, but pressure on public budgets has compelled governments to find alternative ways of providing these facilities. However, contrary to three decades ago, nowadays institutional investors are increasingly interested in infrastructure.

When institutional investors recognised infrastructure for the first time as a financial asset that could improve the risk/return profile of their overall portfolios, the concept of infrastructure investments and project finance entered into the infrastructure literature. This led to the appearance of the infrastructure market and the acknowledgement that infrastructure could represent a new financial asset class with the same risks and investment opportunities that were now coming to light for investors. To this extent, the financial industry redefined infrastructure not in terms of its physical characteristics, but rather on the basis of its specific economic and financial characteristics.

2.1.1 Characteristics of Infrastructure assets

One key characteristic of infrastructure assets, which distinguishes them from all other traditional assets, is that they usually operate as a natural monopoly. Under a natural monopoly model, efficient cost optimisation occurs if there is only one firm responsible for the entire output of an industry (Mackay-Fisher, 2012). As such, infrastructure assets usually have one or more of the following characteristics: high barriers to entry, economies of scale, inelastic demand, and long-duration (Inderst, 2009). These characteristics convey many attractive investment features to the infrastructure assets, including:

- Attractive financial performance (superior risk-adjusted returns, secure and stable cash flows),
- Low correlation with macroeconomic conditions,
- Inflation hedging properties, and
- Low correlation to other assets

As a result of the strong interest in infrastructure, there are many infrastructure projects, listed infrastructure funds, companies, and unlisted infrastructure funds from which to examine the investment characteristics of this asset class (Oyedele et al., 2013, Peng and Newell, 2007). Due to scant data on unlisted infrastructure, research conducted in this area has for the most part taken place within the industry (CFS, 2009, RREEF, 2007). Academic research in this area is therefore new and is still mostly driven by listed infrastructure performance.

2.2 Attractive Financial Performance

2.2.1 Listed Infrastructure

The emergence of infrastructure as a new asset class led to the development of a number of listed infrastructure indices designed to represent the performance of the listed infrastructure market. These indices correspond to listed transport utilities, telecom, and energy firms, in addition to listed infrastructure funds, and were created to deliver a market capitalisation weighted proxy of the performance of the listed infrastructure sector (Blanc-Brude, 2013). The listed infrastructure space is situated mainly in Australia, the US and Europe, as most privatisation programmes have occurred in these countries, and it has witnessed significant growth in recent years. For example, in 1980 only 216 companies had or owned an infrastructure concession that generated more than 50% of their revenues, but by 2010 the number rose markedly to 1,458 companies (Rothballer and Kaserer, 2012). More recently, listed infrastructure indices show capitalisations of more than $3tr in 2015 (Waine, 2015).

Risk/Return performance

A study by Deutsche Bank asset management unit (RREEF, 2007), evaluated the performance of global returns for 10 years, between 1997-2007, among alternative assets and traditional assets. The authors defined alternative assets as illiquid assets with a limited investment history, as uncommon to include in portfolios, and as assets requiring specialised managerial knowledge. Infrastructure is included in the alternative assets category, and the authors used two UBS listed infrastructure indices (UBS Infrastructure and UBS Infrastructure and Utilities) in order to analyse the performance of infrastructure. Their results indicated that, in terms of the Sharpe ratio, infrastructure performed better than public equity and fixed income, but was outperformed by private equity, hedge funds and real estate.

Using an asset-liability model, Morgan Stanley Asset Management (Anne and Sadek, 2007), compared five asset classes (infrastructure, bonds, equities, real estate and private equity) from 1992-2007; in their study they demonstrated that infrastructure falls behind bonds in terms of volatility, and behind private equity in returns. Morevover, Idzorek and Armstrong (2009) used a variety of infrastructure indices to examine the performance of infrastructure from 1990 to 2007. They created three indices that vary in their levels of utility exposure (Low Utilities, Average Utilities, and High Utilities). On a risk-adjusted basis, as shown by the Sharpe ratio, all three infrastructure indices were outperformed by global private equity, US bonds and global high yields, but infrastructure outperformed cash, non-US bonds, stocks, real estate, and futures. It is noteworthy that RREEF (2011) study has also focussed on the performance characteristics of listed infrastructure by including in its analysis the period of the financial crisis. Using a Dow Jones Brookfield Global Infrastructure Index, the research demonstrates that listed infrastructure performed better in terms of returns than most major asset classes (stocks, bonds, listed real estate, and private real estate) from 1, 3 and 5-year perspectives, ending in June 2011. This clearly shows that infrastructure is a defensive sector and investors can benefit from its predictable cash flows and high returns. In terms of risk-adjusted returns, the research indicates a better Sharpe ratio for infrastructure than for all other asset classes except bonds.

Bird et al. (2014) using UBS indices on the whole infrastructure as well as an index on infrastructure and utilities, illustrated that listed infrastructure shows evidence of excess returns from 1995-2009. Furthermore, they find that listed infrastructure has much higher volatility than listed utilities. Similarly, Sawant (2010b) demonstrated that infrastructure indices exhibit negative skew, high kurtosis and high volatility. He concluded that listed infrastructure equity indexes fail to provide a good representation of the underlying infrastructure. Peng and Newell (2007) evaluated the performance of listed infrastructure, by obtaining from UBS, returns on 16 listed infrastructure funds and 16 listed infrastructure companies. For the period Q3.1995-Q2.2006, Peng and Newell (2007) found average annual returns to be 22.4%, which was higher than the return of unlisted infrastructure:

14.1%. However, the higher returns for listed infrastructure came at the expense of higher volatility. In fact, listed infrastructure presented the highest volatility of all assets (16.03%). Nevertheless, they also show that the Sharpe ratio of listed infrastructure outperforms the market.

In a similar study but for a different country, Newell and Peng (2008) examined the role of US infrastructure in an investment portfolio for the period Q1.2000-Q4.2006. They used two infrastructure series: US Infrastructure, comprised of 4 companies/funds at $27 billion, and US Utilities, comprised of 94 companies and funds at $633 billion. These were compared to Global Infrastructure and Utilities, real estate, stocks, REITs, and bonds. In terms of risk-adjusted returns, US Utilities were outperformed by all assets except stocks, while US Infrastructure was the worst performing asset on a risk-adjusted basis (Newell and Peng, 2008). US Infrastructure and US Utilities were outperformed by their global equivalents, which indicates the extent to which the US was lagging behind Europe and Australia in global infrastructure development. The aforementioned finding also tells us that the geographic location of infrastructure is important when assessing the financial performance, as there is heterogeneity among countries. This is important as one need to be aware of the heterogeneous nature of the regulation between sectors and countries. For instance, each country has its own PPP regulation. While in Canada, the PPP market is mature and there is a tendency to push for PPP procurement on any projects over CAN 100m in the U.S. the federal government only recently started to taking steps in making the PPP legislation more acceptable to stakeholders (Infra Deals, 2017). Another example of a difference in legislation between sectors and countries is the example of Germany and nuclear powers. While Germany has a new legislation that wants to shutdown nuclear powers by 2021, in most of the rest European countries nuclear power plants are still in operation.

At present, research on the European infrastructure market is scant. For instance, in 2010 the RREEF study was one of the few available analyses on the performance of European listed infrastructure assets. The indices included UBS Developed Infrastructure & Utilities Europe, UBS Developed Utilities infrastructure, UBS Developed Infrastructure Europe, and Dow Jones and Brookfield Infrastructure

Europe. The study demonstrated that the medium to long-term performance of infrastructure shows less volatility than the 1-year and 3-year returns. Focussing on the 10-year performance (up to June 2010), the results showed that the UBS Developed Infrastructure Europe index yielded the highest return among other asset classes such as stocks, bonds, real estate (public and private) and private equity, but in terms of volatility is outperformed by bonds, real estate (private) and private equity. On the other hand, the UBS Europe Infrastructure & Utilities index outperforms most assets in terms of returns except for private equity; however, in terms of volatility, it is outperformed by all assets except stocks and real estate (RREEF, 2010).

The only study to have examined the performance of infrastructure in the United Kingdom is Oyedele (2014). Using indices from Thomson Reuters, the author compared the performance of listed infrastructure as captured by the following indices: UBS UK infra, UBS UK infra and utilities, UBS UK utilities with UBS UK ports, and UBS UK water, along with the traditional assets, such as UK property, private equity, hedge funds, stocks, and government bonds for a 10-year period (2001-2010). The study results indicate that UK infrastructure performed better than UK property, private equity, hedge funds, stocks, and ports; however, UK infrastructure was outperformed by the sub-sectors UK Utilities and UK water (Oyedele, 2014).

Sectors and Sub-sectors

RREEF (2010) investigated at the global level the risk and return of sub-sectors for the period 2000-2006. Their results make plain the differentiation between sub-sectors with ports, toll roads and water utilities showing a positive return of above 20%, while for the same period sub-sectors such as communications and diversified utilities yield a negative return. Rothballer and Kaserer (2012) carried out a study of the risk profile of listed infrastructure companies. Using the aforementioned 1,458 infrastructure firms from 71 countries across a range of infrastructure sectors such as transport, utilities and telecom, the authors compared the risks of these with non-infrastructure stocks from 1995-2009. The unexpected results of Rothballer and Kaserer (2012) indicated that the volatility of infrastructure was not lower than other MSCI stocks, even though the authors observed significant variation among the sectors. For instance, telecom sub-sectors showed high volatility of around 50% while utilities had lower volatility of 32%. In the same 2012 study, differentiation among the sectors is once again remarkable. Telecom shows higher market betas whereas transport and utility betas are significantly lower.

In accordance with the research discussed here, we can confirm that infrastructure should not be treated as a single asset class and that particular attention should be paid to other factors as well as the sector of the investment when assessing the risk profile an infrastructure investment (Rothballer and Kaserer, 2012). Oyedele et al. (2013) also examined the performance of listed infrastructure over a 10-year period (2001-2010) in addition to the significance of listed infrastructure in a mixed-asset portfolio. The work of Oyedele et al. (2013) stands out as one of the few European studies to also provide some sub-sector analysis performance. These authors have tested the performance of UBS indices on toll roads, airports, ports, power generation, integrated utilities, and integrated regulated utilities. Results of their research indicated that European infrastructure shows an attractive annualised return and an acceptable volatility; moreover, it out-performed traditional assets such as European stocks and European REITs but performed poorly compared to European bonds.

Discussion of listed infrastructure performance literature

Much of this research has indeed demonstrated a source of superior risk-adjusted returns of listed infrastructure in comparison to other more traditional assets. The academic literature has attempted to explain these excess returns. Many scholars assert that leverage is the cause of the existence of excess returns in listed infrastructure. Bird et al. (2014) have demonstrated that listed infrastructure demonstrates negative skew and positive kurtosis, and that all these are indicators of high debt levels. Furthermore, the authors argue that infrastructure funds are also leveraged, something that creates a second layer of debt since the underlying assets are already highly leveraged (Bird et al., 2014). Another cause for the excess returns illustrated in the literature is regulatory risk, as regulation will drive owners to sacrifice supernormal profits if they lead to welfare losses (Ho and Liu, 2002). Guasch and Spiller (2001) have estimated that regulatory risk may lead to a risk premium of the cost of capital between 2% and 6%. However, the durability of these excess returns has been questioned by other authors. By collecting 30 Australian IPOs in the infrastructure sector between 1996 and 2007, the study of Dimovski (2011) illustrated that under-pricing is not statistically different from zero. Thus, the reduced prices in Australia during the 1990s have not persisted, as demand for infrastructure assets has increased and investors better understand the nature of the infrastructure market. Similarly, Bird et al. (2014) also demonstrated that the excess returns found in the listed Australian market have reduced in recent years, suggesting that excess returns are not persistent over the long-term.

One observation from the literature is that infrastructure assets are heterogeneous and more research is needed on the specific performance of listed infrastructure sectors and sub-sectors. Many of the listed infrastructure indices used in the above studies are dominated by utilities. This is shown by the UBS World Infrastructure index (that excludes utilities), which had a capitalisation of $200bn in 2012; meanwhile, the UBS Word Infrastructure and Utilities index had a capitalisation of $1.4tr. We can therefore surmise from our literature review that there is also a gap in the literature with regard to the behaviour of the different infrastructure sectors and sub-sectors that need to be addressed. The established definition of infrastructure has prevented researchers from recognising that infrastructure is actually a vast and complex asset class requiring a deeper evaluation of its underlying sectors and sub-sectors. Importantly, research should be conducted using listed indices on specific sectors and sub-sectors.

2.2.2 Unlisted Infrastructure

Unlisted infrastructure funds originated in Australia during the 1990s and have gained momentum in recent years. While listed infrastructure is an indirect indication of the infrastructure market, unlisted funds invest directly in infrastructure projects. Thus, studying unlisted data gives more precise information on the performance characteristics of the infrastructure market. However, due to data scarcity, research on unlisted data is still in its infancy.

Risk/Return performance

As previously discussed, Australia has relevant and available data on infrastructure due to its significant experience with unlisted infrastructure funds. Mercer (2005*b*) has investigated the performance of unlisted infrastructure in Australia. The author observed that between 1996-2005 the average annual return of unlisted infrastructure was 13.3%, with 9.1% volatility. Mercer (2005*a*) found that this compares favourably with other traditional assets, because for the same period equities showed 11.6% return and 11.3% volatility. The first academic study on the performance of infrastructure funds was carried out by Peng and Newell (2007), who collected data on 19 unlisted infrastructure funds in order to evaluate the performance of unlisted Australian funds, using an equally-weighted index of 5 of the 19 major Australian unlisted funds. For the period between Q3.1995-Q2.2006, Peng and Newell (2007) found average annual returns at 14.1% for unlisted infrastructure. Unlisted infrastructure fund performance achieved higher average annual returns from Listed Property Trusts (LPTs), Real Estate Investment Trusts (REITs), stocks, direct property, and bonds. The annual volatility of unlisted infrastructure funds was 5.83%, higher than direct property and bonds but had lower volatility than (LPTs) and stocks.

Kaserer et al. (2009) analysed the risk/return characteristics of direct investments in unlisted infrastructure companies within funds. They derived two different data sets from the private-equity database for the period 1986-2007. Data set I is narrow, and includes funds where the word infrastructure appears on the name of the fund, whereas data set II is wider, in which funds included have an infrastructure or a mixed focus. The results on data set I indicated average gross IRR, for 196 realised transactions at 48.0% and 14.3% for 187 unrealised investments. In data set II, the average gross IRR for 478 realised transactions was 34.2% and for 355 unrealised transactions was 45.5%. Kaserer et al. (2009) concluded that, in general, infrastructure has high absolute returns and low volatility relative to other assets. Using Preqin data from 1993-2007, Inderst (2010) compared the risk/return performance of 37 global unlisted infrastructure funds with buyout, venture, real estate, and mezzanine. The 17 years is divided into three periods, as not all funds were operating since 1993; the majority of the funds were launched in the 2000s. The three periods are 1993-99, 2000-04 and 2005-07. For the period (1993-99), median IRR for infrastructure was 9%, which was close to all other funds examined but was slightly outperformed by buyout and real estate. In terms of volatility, median IRR illustrated a dispersion of 16.5%, which was well below buyout and venture but higher than real estate and mezzanine. In the second period (2000-04), median IRR was 8.8%, close to mezzanine, well above venture but well below buyout and real estate. The volatility of the second period was only 11.8%, lower than all other funds except mezzanine. Lastly, in the third period (2005-07), infrastructure showed positive returns that were superior to all other funds which, with the exception of mezzanine, indicated negative or close to negative returns. Similar to the previous period, its volatility was lower than all other funds except mezzanine, at 15.4%.

Another interesting study conducted by CFS (2010b), confirmed that unlisted infrastructure in Australia has performed consistently well. For the 10 years ending in June 2010, on a risk/return basis the unlisted infrastructure was outperformed by unlisted property only, but performed better than equities, fixed income, listed infrastructure, and REITs. Newell et al. (2011) repeated their 2007 study for the period Q3.1995-Q2.2009 in order to account for the years of the Global Financial

Crisis (GFC). Using five main unlisted infrastructure funds in Australia that account for the 30% of the unlisted infrastructure sector in the whole country, the authors created an Australian unlisted infrastructure series to track the performance of the unlisted infrastructure sector (Newell et al., 2011). For the whole data set their results verified that unlisted infrastructure was the second-best performing asset in terms of returns, given that it was only outperformed by listed Australian infrastructure. Both listed and unlisted infrastructure outperformed global infrastructure, Australian REITs, stocks, bonds, and direct property. In terms of risk though, unlisted infrastructure had a significantly lower volatility of 6.27% compared to listed infrastructure, which had a volatility of 24.64%. In relation to other asset classes, unlisted infrastructure had lower volatility than all other assets except direct property. Similarly, on a risk-adjusted basis, unlisted infrastructure was only outperformed by direct property, thus illustrating a higher Sharpe ratio for both listed Australian infrastructure and listed global infrastructure. Bird et al. (2014) applied a robust factor model using US and Australia infrastructure and utilities returns to examine the performance characteristics of infrastructure. For unlisted infrastructure, they constructed an equally-weighted index that captures return data for 105 unlisted infrastructure assets. Their results indicate that, similar to the listed infrastructure market, there are excess returns in both the US and Australia unlisted infrastructure market. They also found that unlisted infrastructure reports positive skew and high kurtosis, the lowest beta and the highest Sharpe ratio (Bird et al., 2014).

In a recent study using the DJ Brookfield Global Infrastructure Index to capture the listed infrastructure performance, World MSCI Index for listed equities, Barclays Global Aggregate Bond Index for government bonds, and IPD Global Infrastructure Direct Asset Index to track the performance of unlisted infrastructure, RREEF (2015), compared the annualised returns and Sharpe ratios on a 1, 3 and 5-year basis. Their results confirm that listed and unlisted infrastructure outperformed both equities and government bonds on a 1 and 5-year basis, with listed infrastructure showing slightly higher returns than unlisted infrastructure. The study also compared the risk-adjusted returns for each asset, with results showing that listed infrastructure provided the second highest Sharpe ratio after unlisted infrastructure for the period 2010-2014 (RREEF, 2015).

Sectors and Sub-sectors

With the exception of a few industry reports showing the differences between the expected returns of different infrastructure sectors (Mercer, 2005*b*), there is no literature to our knowledge that examines the heterogeneity between the different sectors and sub-sectors of unlisted infrastructure. Infrastructure is a new vast asset class consisting of many different sectors, each with its own features and historical performance. As Hall et al. (2014) argued, one of the major challenges in understanding the long-term performance of infrastructure is to get to grips with the complexity of the sector.

Secure stable cash flows

We begin with the research of Bitsch et al. (2010), who used data on 363 infrastructure deals and 11,223 non-infrastructure deals, between 1971-2009, to examine the risk, return and cash flow features of unlisted infrastructure. They found that infrastructure has a number of specific characteristics, such as lower default rates and better inflation hedging properties than the traditional assets. However, their research rejects the hypothesis that infrastructure fund cash flows are more stable than non-infrastructure fund cash flows. Furthermore, they examined the differences between brownfield and greenfield investments and concluded that brownfield investments are less risky, as evinced by their lower default frequencies. Additionally, they argued that brownfield investments offer higher returns, and this is robust for all measures of returns used (IRR or other multiples).

Another study to have examined cash flows is the JP Morgan Asset Management report (2008), where they used the cash flows of EBITDA for 256 US infrastructure companies from 1986-2008 in order to examine their volatility and their correlation with other assets. The JP Morgan report concluded that cash flows of infrastructure are less volatile than corporate equities and real estate (J.P. Morgan, 2008). Around the same time, Kaserer et al. (2009) investigated other patterns of infrastructure cash flows. By investigating the cash flows of direct investments in unlisted infrastructure companies by infrastructure funds between 1986-2007, they found that greenfield investments are more often investment targets than brownfield investments. Moreover, in the study, the total investment duration showed a median of 41 months and 37 months of amortisation. The wide variation across each deal is also worth mentioning. Thus, Kaserer et al. (2009) have concluded that cash flows of infrastructure are not uniform across all deals, and that neither greenfield nor brownfield has stable cash flows, as expected.

To sum up, there is evidence to confirm that unlisted infrastructure indeed has superior risk/returns. Many researchers argue that the source of the excess returns is leverage. Nevertheless, until now researchers have not investigated the multi-factor causation for the different sources of excess returns, i.e. political risk, illiquidity and leverage. Due to scant data and the lack of transparency of the market, there is not yet sufficient information on the performance of unlisted infrastructure fund investment. We therefore address this topic in the present thesis, with the aim to help boost the confidence of institutional investors regarding these investments.

2.3 Low correlation with macroeconomic conditions

One important characteristic of infrastructure assets is that they are assumed to have low dependence on macroeconomic conditions, thus guaranteeing the resilience of infrastructure returns during periods of low economic activity (Inderst, 2009). Nevertheless, there is little evidence to support the risk insurance characteristics of infrastructure. The next section examines studies that have applied data during periods of crisis in order to compare the performance of infrastructure with other traditional assets.

2.3.1 Listed Infrastructure

Oyedele (2014), has examined the defensive characteristics of UK infrastructure during the global financial crisis of 2008. The risk insurance properties of infrastructure are confirmed by his study as different from government bonds, where UK infrastructure is the only asset to have shown positive annualised returns and a positive Sharpe ratio. Furthermore, Oyedele et al. (2013) examined the performance of European infrastructure during the financial crisis period, and in so doing they considered differentiation components among the various infrastructure sub-sectors, such as ports. Infrastructure showed negative annualised returns and high volatility but the infrastructure sector had an overall better performance than stocks.

In evaluating the defensive characteristics of infrastructure, one should also bear in mind the amount of leverage of these investments. After 2008 there were listed Australian infrastructure funds that had to be restructured in order to meet their debt obligations, as in the case of Macquarie; others had to be liquidated, as in the case of Babcock & Brown (Tucker, 2008, Ubhi, 2008). Is the low correlation with macroeconomic performance eroded by the excess correlation with the credit cycle? This subject, although critical, is not within the scope of the present research.

2.3.2 Unlisted/Direct Infrastructure

Macquarie (2008), argued that infrastructure has shown stable and strong performance regardless of economic events. Using data from the international Civil Aviation Organisation, they demonstrated that, from 1970 to 2006, airport traffic growth continued to rise despite shock events: the recession of the 1980s, the Gulf War and the 9/11 terrorist attack. They argued that investing in infrastructure is a good strategy for investors who invest heavily in the UK equity market as a complement to commercial property, as a way to diversify their portfolios from global equity, and as a hedge against inflation. Although they did not reach consensus about investor allocations into infrastructure, usually an allocation of 3%-5% is considered to be adequate.

By extending their 2007 data to include the period of the financial crisis (GFC), Newell et al. (2011), contracted their data set to isolate the period of the GFC from Q2.2007 to Q2.2009. Their results show convincingly that unlisted infrastructure is the best performing asset with a Sharpe ratio of 0.32, followed by bonds with a Sharpe ratio of 0.15. The impact of the GFC is evident in all of the other asset classes, which also show a negative Sharpe ratio. Thus, one can conclude that the defensive characteristics of unlisted infrastructure are confirmed by the study of Newell et al. (2011). Contrary to the above study, however, Bird et al. (2014), find no evidence of defensive characteristics. The performance of both US and Australian infrastructure assets showed deteriorating effects during bad macroeconomic conditions.

2.4 Inflation-hedging properties

Infrastructure is also assumed to be a hedging strategy against inflation due to its monopolistic pricing power, and as a result of regulatory or contractual agreements that allow for increased tariffs along with inflation (Colonial First State (CFS), 2006, Orr, 2007, Rickards, 2008, RREEF, 2005, Williams, 2007). The theoretical justification for these propositions is fairly straightforward to understand. Due to the monopolistic pricing power of infrastructure assets, infrastructure players are able to pass any increase in price onto consumers since infrastructure is considered to be price-inelastic. Thus, if an increase in inflation will not lead to a decrease in volume, the revenues earned from infrastructure are thought to be inflation-linked (RREEF, 2005). The second theoretical justification is that under many regulatory regimes prices are adjusted annually and they are in line with inflation rates

(CFS, 2009). Yet this often cited assumption is not much supported empirically and the evidence in the literature is inconclusive (Martin, 2010, RREEF, 2015). There are studies that do not find a strong link between infrastructure (Peng and Newell, 2007, Sawant, 2010b), while others do find supporting evidence of inflation hedging abilities (Armann and Weisdorf, 2008, Bird et al., 2014, Bitsch et al., 2010, Van Antwerpen, 2010, Wurstbauer and Schäfers, 2015). As the inflation-hedging properties of infrastructure are not within the scope of this study, we will not explore this aspect in detail.

2.5 Low correlation with other assets

Another key point relates to the correlation with other assets, in that diversification can be achieved by investing in assets with a low correlation of returns. The analysis of correlation is heavily constrained by lack of data in the unlisted sector, so most of the studies we include use listed infrastructure indices.

Mercer (2005*a*) shows low correlations of less than 0.20 between unlisted infrastructure and other assets, and 0.30 against unlisted real estate. RREEF (2007) show that listed infrastructure has a negative correlation with bonds but it moves with general stock market volatility. The indication here is a moderate correlation between listed infrastructure funds and stocks. Peng and Newell (2007) studied the potential role of infrastructure in portfolios by looking at the correlation of both listed and unlisted infrastructure with other assets. Their results interestingly showed that listed infrastructure has higher correlation with other assets compared to unlisted infrastructure. For instance, Peng and Newell (2007) estimated that listed infrastructure has a correlation of 0.21 and 0.38 with equities and bonds respectively, but a correlation of 0.03 with direct property; whereas unlisted infrastructure has lower correlations with equities and bonds of 0.06 and 0.17 respectively, but a higher correlation of 0.26 with direct property. Their results validate the potential portfolio diversification benefits that could be gained by including infrastructure in a portfolio also containing other assets, particularly unlisted infrastructure. The correlation results of Anne and Sadek (2007) show low correlations with all other assets.

A later study of Newell and Peng (2008) found lower correlation between US infrastructure and its global equivalent (r=0.53), compared to US utilities with Global Utilities (r=0.92). According to Newell and Peng (2008), US infrastructure presents more portfolio diversification benefits than US utilities, as infrastructure has a low correlation with US real estate and US REITs of 0.28 and 0.23, respectively. Looking at a similar analysis but for 35 Hong Kong listed infrastructure companies for the period 1995-2006, Wang et al. (2009), confirmed that infrastructure demonstrates some low market correlation but high volatility. Idzorek and Armstrong (2009), verified that the three infrastructure indices used in their study are most correlated with equities and real estate, and negatively correlated with commodities.

J.P. Morgan (2008) found that infrastructure cash flows are negatively correlated with equities and weakly correlated with real estate. In their follow up study, J.P. Morgan (2010), using 10-year returns prior to 2008, showed that infrastructure exhibits low correlation with all the asset classes examined, which were US Treasury, Munis, US Large Cap, EM equities, and direct real estate.

In another asset comparison, Bitsch et al. (2010) reported strong correlation between unlisted infrastructure funds and private equity. Sawant (2010a) examined infrastructure project bonds across 15 countries and showed that these instruments indeed have diversification potential with equities and commodities. CFS (2010b) examined the correlation with other assets between 2000-2010, and found that unlisted infrastructure shows very low correlation with fixed income, equities and listed property.

The authors of a CSAM (2010) study used two infrastructure indices to examine the correlation with other assets: the Macquarie Global Infrastructure Total Return Index, which reports 48 global publicly listed funds, and a customised infrastructure index that accounts for returns on airports, ports and energy infrastructure. The research indicated low correlation between infrastructure and all other asset classes except for non-US equities, from July 2000 to March 2010. Finkenzeller et al. (2010) examined the correlation between direct (unlisted) and indirect (listed) infrastructure and other asset classes for the period Q4.1994 to Q1.2009. For the indirect infrastructure, the authors used a UBS Australia Infrastructure & Utility Index, while for the direct infrastructure they used a Colonial First State Index covering the performance of five Australian funds. Their results showed a correlation of 0.20 between direct infrastructure and direct property, which weakens to 0.04 when the period of the financial crisis is examined (Q3.2007 to Q1.2009). They also found a higher correlation of 0.54 between indirect infrastructure and the NAREIT index. The high correlation between indirect infrastructure and the NAREIT index is expected, as indices used report listed companies that are vulnerable to changes in the equity market. These correlations lead the authors to conclude that infrastructure should be distinguished from real estate and be treated as a separate asset class. In a follow up study, Dechant and Finkenzeller (2013) used an index composed of US operating infrastructure projects in order to examine the correlation among direct infrastructure with other assets such as government bonds, real estate, corporate bonds, and small and large cap stocks. Their results yielded low correlations among direct infrastructure and all assets except for large cap stocks. The authors justify the high correlations with large cap stocks as normal, as both assets are expected to have similar behaviour over the long-term. Large cap stocks are stocks of companies with monopoly power, stable dividends and low growth rates, characteristics which are similar to those of infrastructure projects.

Newell et al. (2011) concluded that, in so far as diversification benefits are concerned, unlisted infrastructure provides significant diversification benefits across all other asset classes, including listed infrastructure. In the Newell et al. study, the portfolio diversification benefits of unlisted infrastructure remained stable over the GFC of 2008, something that proves the robustness of unlisted infrastructure, particularly in relation to listed infrastructure.

RREEF (2015) carried out a recent study of the correlations between listed and unlisted infrastructure, global bonds and listed equities. Their results confirmed that for 2010 to 2014, unlisted infrastructure showed a negative correlation with global bonds of -0.25, listed infrastructure -0.12 and listed equities of -0.20.

Sectors and Sub-sectors

One of the few studies on the correlation between sub-sectors was done by (J.P. Morgan, 2008, 2010) where they examined historical correlations of different US sub-sector companies for the years 1986 to 2006. Their results indicated that infrastructure assets are not highly correlated against each other, thereby suggesting a diversification benefit within the asset class. However, when Oyedele et al. (2013) examined European infrastructure sub-sector correlation for the years 2001 to 2010, the authors found high correlations among the infrastructure sub-sector companies.

The implication of the studies discussed in this section is that infrastructure assets can be used as a shock absorber within a portfolio. Since infrastructure moves independently, it can offer moderate to high returns at times when other assets' returns are decreasing. In the next section we review studies that examine infrastructure investments within an institutional portfolio.

2.6 Infrastructure and the Institutional Portfolio

Many scholars and industry reports have tested the effect of infrastructure within a portfolio and identified how much an investor should allocate to infrastructure.

The asset-liability model of Anne and Sadek (2007) was further applied to calculate the optimal allocation of infrastructure in a portfolio with all other asset classes. Their findings indicated that infrastructure improves the risk/return ratio in a portfolio, with the most favourable risk/return ratio arising when increasing the investment of infrastructure to 15%. RREEF (2007) delved deeper into the role of alternatives in a traditional portfolio of stocks and bonds and verified that, by using alternative assets, a portfolio's risk-adjusted returns are improved. The authors' alternative portfolio, including investments in stocks, bonds, direct real estate, private equity, hedge funds, and 5% in infrastructure, indicated that between 1998 and 2006, the return on the portfolio was 9.6%. This percentage exceeds the traditional portfolio's return by 150 basis points. The alternative portfolio also had a volatility of 12.0%, 170 basis points lower than the volatility of the traditional portfolio. However, the improved risk-adjusted returns in this research are due to the addition of all the alternative assets in the portfolio, as the authors did not examine the significance of infrastructure by itself in portfolios. Bond et al. (2007) used the Macquarie Global Infrastructure Index for the period 1997 to 2006 and concluded that neither commodities, hedge funds nor direct infrastructure reduce risk as much as property when allocated in a UK portfolio of traditional assets.

Furthermore, Idzorek and Armstrong (2009) have conducted several historical-portfolio Markowitz optimisations, in addition to a forward-looking optimisation, by considering several CAPM assumptions; in so doing, they demonstrated that the optimal allocation for infrastructure lies between 0% and 6%. CFS (2010b) discussed the benefits of including unlisted infrastructure in a portfolio and argued that adding unlisted infrastructure to a traditional portfolio reduces the volatility of the portfolio rather than increasing its returns. Specifically, by adding 10% of unlisted infrastructure to a portfolio of equities, fixed income, unlisted property, REITs, and listed infrastructure lowers the risk of the portfolio from 6.27% to 5.71%, while increasing the return of the portfolio from 6.95% to 7.15%. The result is a return/risk ratio of 1.25, compared to 1.11. Sawant (2010b), inserts different listed infrastructure indices into portfolios of only bonds and stocks. His results indicated that adding an allocation to infrastructure indices will enhance portfolio returns and the risk/return of a portfolio as infrastructure indices will yield higher returns to stocks.

In a CSAM (2010) study assessing the impact of infrastructure on institutional investor portfolios, the authors created three scenarios to demonstrate the impact of adding different allocations to infrastructure in the return and risk of an institutional pension portfolio of 43% equities, 24% fixed income and 33% alternatives, which has a return of 8.80% and a risk of 11.70%, yielding a Sharpe Ratio of 0.75 (CSAM, 2010). The first scenario added 2.5% of infrastructure (at the expense of reducing the allocation to equities); this kept the portfolio return constant but decreased the risk of the portfolio by 20 basis points from 11.7% to 11.5%. In the second scenario, the authors showed that by adding 5% of listed infrastructure to an institutional pension portfolio of 43% equities, 24% fixed income and 33% alternatives, the return of the portfolio remained the same at 8.8% but the target risk fell from 11.7% to 11.4%. Last but not least, in the third scenario the authors again added 5% of global listed infrastructure, but this time they also added 5% of customised infrastructure. The result is both an increase in the portfolio's return by 30 basis points, from 8.8% to 9.1% and a decrease in the risk level of the portfolio by 40 basis points, from 11.7% to 11.3%. The efficiency of the portfolio captured by the Sharpe ratio increased from 0.75 to 0.80. Another study by RREEF (2011) assessed the role of listed infrastructure in the risk/return of a multi-asset portfolio. Using returns of more than eight years, the findings of this research verified that using listed infrastructure in a portfolio of bonds and stocks can achieve superior risk-reward outcomes. The authors maximised the returns of three portfolios of three different volatilities, 15%, 25% and 35%. They repeated each analysis twice, one without and one with infrastructure. In all three cases their results confirmed that by including infrastructure in the portfolio investors can indeed achieve enhanced risk/return results. It is worth mentioning that the allocation of listed infrastructure in the portfolio comes at the cost of subsidising stocks.

Moving away from research on global and US infrastructure, Oyedele (2014) studied the performance of UK infrastructure by examining the significance of UK infrastructure performance in portfolios. Using a mean-variance optimisation, the author concluded that, by adding listed UK infrastructure into a traditional portfolio, better portfolio returns result for the same amount of risk. Furthermore, the portfolio results of Oyedele et al. (2013) on European investments demonstrated that infrastructure plays a significant role in the optimality of mixed asset portfolios. The incurred benefits are, however, due more to enhancing returns than to a reduction in risk (Oyedele et al., 2013).

One of the difficulties in dealing with the optimisation of alternative assets is that alternative assets usually do not have normal returns; therefore, the use of traditional optimisation techniques is not adequate. To date, there is very little research using alternative risk management optimisations when examining the behaviour of infrastructure in the portfolio context. For instance, Finkenzeller et al. (2010) investigated the significance of listed and unlisted infrastructure in portfolios. For the Listed and unlisted infrastructure data the authors used a Bloomberg and a Colonial First State index respectively. With historical returns to calculate the optimal infrastructure allocation, they used an optimisation that accounts for the downside risk of these investments defined by the semi-variance subject to a benchmark. The authors followed this approach in order to accommodate the preferences and behaviour of investors: something that is ignored in Modern Portfolio Theory (MTP). The allocations of listed and unlisted infrastructure vary, from 0% to 85%, depending on the level of returns; however, the main conclusion of Finkenzeller et al. (2010) is that low-risk investors should include unlisted infrastructure in their portfolios, whereas high-risk investors should include listed infrastructure. In a follow-up study, Dechant et al. (2010) used the lower partial moment (LPM) to employ a downside risk optimisation in order to compare the relationship between real estate and direct infrastructure. For this analysis, the direct infrastructure data is an index provided by CEPRES, and comprised of 788 individual operating infrastructure projects in the US. Using a data set from Q2.1990-Q2.2009, the authors found that direct infrastructure is important in the diversification of an investor's portfolio. Furthermore, Dechant and Finkenzeller (2013) have examined the significance of real estate in the multi-asset portfolio along with the role of US infrastructure. The authors argued that the allocation of real estate may be particularly affected when infrastructure is included in the portfolio, as the two assets are supposed to offer identical characteristics, which is something that could lead investors to pursue a trade-off between both assets. Thus, Dechant and Finkenzeller (2013) were keen to investigate the role of both infrastructure and real estate in a portfolio. To account for non-normality, the authors employed a mean-downside risk (DR) portfolio. They used quarterly US returns from the following assets: real estate, indirect infrastructure, stocks, commodities, REITs, government bonds, cash, direct infrastructure, and private equity. The index used for real estate was the TBI index; the data used for direct infrastructure are an index containing 930 individual US infrastructure transactions and the UBS US Infrastructure & Utilities index for indirect infrastructure from Q2.1990-Q2.2010.

The results of the Dechant and Finkenzeller (2013) study emphasised the importance of direct infrastructure in portfolios, and also showed that when infrastructure is not included in the portfolio, the allocations to direct real estate are overestimated. Both direct real estate and direct infrastructure are good investments in bear markets, while indirect infrastructure has proved to be an important component in bull markets as well (Dechant and Finkenzeller, 2013). In a 2012 study, Dechant and Finkenzeller (2012) demonstrated the role of direct infrastructure in a portfolio that includes US total return data from 9 asset classes: direct real estate, direct infrastructure, large and small cap stocks, 4 bonds of various maturities, and cash for the period Q2.1990-Q2.2010. To capture the performance of direct infrastructure, the authors applied the same index they use in 2013, which includes 930 US infrastructure projects; for direct real estate, they used the TBI Index, and all remaining assets were obtained from Thomson Reuters DataStream.

Dechant and Finkenzeller (2012) applied a standard mean-variance analysis; to account for non-normality of returns they used an algorithm to minimise the Conditional Drawdown at Risk (CDaR) for a given expected return. In order to capture time variation in the behaviour of assets, the authors re-balanced the portfolio each month starting from April, 1996. For each optimisation they projected 10 efficient portfolios for different levels of risks. The first portfolio was the minimum risk portfolio while the tenth portfolio was the maximum return, with eight portfolios in between. They found that direct infrastructure is mainly a good component of the portfolio for low and medium risk portfolios with allocations of 32%

and 28%. Direct infrastructure is also good for investors seeking long investment periods. Moreover, similar to Dechant et al. (2010) and Dechant and Finkenzeller (2013), the authors confirmed that real estate and infrastructure are not substitutes, since the inclusion of infrastructure in the portfolio did not strongly affect real estate weightings. Thus, the authors asserted that direct infrastructure can play a significant role in a portfolio and offers a better risk/return trade-off than a traditional portfolio consisting of bonds, stocks and real estate. The authors concluded that infrastructure is a good choice for people who want to protect the shortfall of their investments and invest over the long-term (Dechant and Finkenzeller, 2012). Another study on US infrastructure was carried out by Bianchi et al. (2014), who reconstructed US listed infrastructure index returns by mapping their performance to systematic risk factors and industry returns from 1927 to 2010. The main finding of their research is that US listed infrastructure had common performance characteristics to US stocks, in that US listed infrastructure had similar returns, correlations and slightly smaller tail risks to US stocks. In addition to examining the long-term characteristics of listed US infrastructure, the authors also examined these investments in a portfolio context. By applying two different optimisation techniques: Mean-Variance and the Mean-Conditional Value at Risk, the authors concluded that infrastructure replaces stocks when added to a portfolio of stocks and bonds because of their higher returns, lower risk and smaller tail risk. Although these differences are small they are, however, big enough to induce investors to re-allocate their investments from stocks to infrastructure assets (Bianchi et al., 2014).

The benefits of including infrastructure in a portfolio is evident in all of the literature, even though most studies, especially when it comes to listed infrastructure, report a benefit in terms of increasing returns rather than reductions of risk in the portfolio.

Table 2.1: Summary of Literature Review that has examined the financial performance of infrastructure

Paper	Period Data	Listed	Unlisted	Other	Diversification	Risk/Return	Inflation Hedging	Crisis
Ho and Liu (2002)	-			x		x		
Guasch and Spiller (2001)	-			x		x		
Mercer (2005*b*)	1996-2005		x		x	x		
Anne and Sadek (2007)	1992-2007	x				x		
Peng and Newell (2007)	1995-2006	x	x		x	x	x	
RREEF (2007)	1997-2007	x			x	x		
Newell and Peng (2008)	2000-2006	x			x	x		
J.P. Morgan (2008)	1986-2006	x			x	x	x	
Macquarie (2008)	1970-2006		x					x
Armann and Weisdorf (2008)	1986-2005			x			x	
Idzorek and Armstrong (2009)	1990-2007	x				x		
Wang et al. (2009)	1995-2006	x				x		
Kaserer et al. (2009)	1986-2007		x			x		
Sawant (2010a)	2000-2009			x		x	x	
Sawant (2010b)	2001-2009	x				x	x	
RREEF (2010)	2000-2010	x				x		
CFS (2010a)	2000-2010	x				x		
CFS (2010b)	2000-2010		x			x		
Inderst (2010)	1993-2007		x			x		

Paper	Period Data	Listed	Unlisted	Other	Diversification	Risk/Return	Inflation Hedging	Crisis
J.P. Morgan (2010)	1986-2006	x			x	x	x	
Van Antwerpen (2010)	1928-2008	x					x	
Martin (2010)	1930-2008	x					x	
Bitsch et al. (2010)	1971-2009		x			x	x	
CSAM (2010)	2000-2010	x			x			
RREEF (2011)	2007-2011	x	x			x		
Newell et al. (2011)	1995-2009	x	x		x	x		x
Dimovski (2011)	1996-2007	x				x		
Bird et al. (2014)	1995-2009	x				x	x	x
Rothballer and Kaserer (2012)	1975-2009	x				x		
Rödel and Rothballer (2012)	1973-2009	x					x	
Finkenzeller et al. (2010)	1994-2009	x	x		x			
Oyedele et al. (2013)	2001-2010	x				x		x
Blanc-Brude (2013)	2003-2012	x				x		
Oyedele (2014)	2001-2010	x			x	x		
Wurstbauer and Schäfers (2015)	1991-2013		x				x	
RREEF (2015)	2010-2014	x	x		x	x		

Table 2.2: Summary of Literature Review that has examined infrastructure assets within a portfolio

Paper	Period Data	Listed	Unlisted	Other	Reduce Portfolio risk	Enhance Returns
Bond et al. (2007)	1997-2006	x				x
Idzorek and Armstrong (2009)	1990-2007	x				x
Sawant (2010b)	2001-2009	x				x
CFS (2010b)	2000-2010		x	x	x	
CSAM (2010)	2000-2010	x			x	x
Finkenzeller et al. (2010)	1994-2009	x	x		x	x
Dechant et al. (2010)	1990-2009		x		x	
Dechant and Finkenzeller (2012)	1990-2010		x		x	
Dechant and Finkenzeller (2013)	1990-2010		x		x	x
Oyedele et al. (2013)	2001-2010	x				x
Bianchi et al. (2014)	1995-2010	x			x	x
Oyedele (2014)	2001-2010	x				x

2.7 Conclusion

Infrastructure is a recent asset class which has not yet been studied in depth. The financial characteristics of infrastructure and its significance in any portfolio are just beginning to receive the attention of industry and researchers. Table 2.1 summarises the literature examining the financial characteristics of infrastructure, while Table 2.2 summarises the literature on the performance of infrastructure in institutional portfolios.

One thing that strikes us from the literature is that, despite the vast majority of assets under the infrastructure umbrella, most of the aforementioned research assumes that infrastructure sectors and sub-sectors have the same distinctive and attractive investment characteristics. However, there is no specific empirical evidence to support such an assertion. On the contrary, there is some research that acknowledges the heterogeneity of infrastructure sectors, but to date, there is no research that has analysed the significance of this heterogeneity at portfolio level. Against this background, it is partly the aim of the present thesis to study each infrastructure sector and sub-sector investment profile. A further important task will be to examine the heterogeneity of the infrastructure sectors and sub-sectors at portfolio level. In this respect, we aim to address such questions as: which infrastructure sectors are best to be allocated in the portfolio and, is it beneficial to create a portfolio based on a single sector. We assert that proving the optimality of portfolios, even when investments are focussed in a single sector, is important, because by doing so, the portfolio manager will still be able to diversify and will at the same time also develop a deeper understanding of the behaviour of the sector. Finally, we have not yet seen a study that makes direct comparisons between a portfolio investing only in listed infrastructure and one investing only in unlisted infrastructure. For this reason, the present thesis aspires to investigate the differences between investing in listed infrastructure and investing indirectly in unlisted infrastructure within the institutional portfolio context. We empirically test the two options using listed infrastructure indices and a unique and comprehensive unlisted infrastructure fund index in order to determine the best strategy for investors.

The research shown in bold in Table 2.1 and 2.2 is more in line with the present thesis. Oyedele et al. (2013) is the only other European study to have examined the allocation of different sectors and sub-sectors in the portfolio context, while the rest of the highlighted studies are the only ones to have applied the same alternative traditional optimisation techniques, but with the application carried out by inserting an infrastructure index into the portfolio. A main aim of this thesis is to apply alternative risk management techniques in order to capture the optimal allocation of different infrastructure sectors and sub-sectors within the portfolio, and to also examine whether a portfolio that invests in a single sector or allocates a fixed proportion into an unlisted infrastructure fund is still an optimal strategy to follow.

The next chapter examines the data and methodology applied in this thesis.

Chapter 3

Data and Methodology

3.1 Data

The listed data used in this thesis is collected from the Thomson Reuters Database. Given that a central focus of the present thesis is listed infrastructure with an emphasis on infrastructure sectors and sub-sectors, the author has collected monthly returns of European and United Kingdom indices over an 11-year time span (2003-2013) for the European and United Kingdom infrastructure sector analysis, and weekly returns of European indices over a 10-year time span (2004-2013) for the sub-sector analysis. For the comparison of listed and unlisted infrastructure presented in Chapter 8, the author uses the same listed European infrastructure indices; however, the data was extended to 13 years (2003-2015) and the returns collected were quarterly.

The constituents of the infrastructure indices used include companies that are participating directly in the infrastructure market. For example, in our transport index, Aeroport de Paris is listed on Euronext Paris and is an airport owner, developer and operator. As of May 2016, Aeroport de Paris has equity holdings in 11 airports internationally, with full ownership of three airports (Infra Deals, 2016*b*). Another example is National Grid plc, which is included in the utilities index. National Grid plc is a major supplier of gas and electricity in the UK, which is currently involved in many infrastructure deals, and is expected to invest a further £39 billion in regulated networks and electricity transmission by 2021 (Chhambria et al., 2015). All the companies in the indices used are listed on European stock exchanges. It is worth noted though that these companies have operations outside the EU such as national grid that has global operations.

For the unlisted infrastructure data, we use a Preqin index showing the performance of 200 unlisted infrastructure funds over an 8-year period, from Q1.2008-Q2.2015. There is no widely accepted unlisted infrastructure index prior to 2008 (AMP Capital , 2014). Consequently, the data period for the unlisted infrastructure index is shorter than that of the listed indices, which highlights the data constraints encountered in the unlisted infrastructure market compared to the listed one.

As mentioned above, the index focusses on 200 individual unlisted infrastructure partnerships from the Preqin infrastructure database with an aggregate capital worth over US$230bn. The investments of the infrastructure funds are spread widely throughout the world and target both brownfield and greenfield projects across all infrastructure sectors.

The index is calculated every quarter using the following formula:

$$\frac{\text{NAV at the end of quarter + distributions during quarter}}{\text{NAV at the start of the quarter + call-ups during quarter}} - 1 \tag{3.1}$$

where,

- NAV is the net asset value of the fund in US$.
- Call-ups during the quarter refers to the drawdown of the committed capital. It is calculated as the cumulative cash called to date at the end of the quarter minus the cumulative cash called to date at the beginning of the quarter.
- Distribution during the quarter is the total money returned to investors (LPs) during the quarter and is calculated by subtracting the cumulative

Table 3.1: Overview of selected indexes for European Sector analysis

Name	Ticker
Thomson Reuters EU Energy Index	.TRXFLDEUPUENE
Thomson Reuters EU Telecommunication Services Index	.TRXFLDEUPUCOM
Thomson Reuters EU Utilities Index	.TRXFLDEUPUUTL
Thomson Reuters EU Transport Infrastructure Index	.TRXFLDEUPUI47
Unlisted Funds Infrastructure Index	PrEQIn- Infrastructure Index
AEX ALL SHARE INDEX	.AAX
Dow Jones EU Selected Real Estate Index	.DWEURS
EU Government Bond Index, 1-3 years	.SBEU13U
Thomson Reuters EU Government Bond Index	.TRXABDGOVAE
Eurotop Index (control)	.EUR
Thomson Reuters EU Real Estate Index(control)	.TRXFLDEUPUF4
EU Government Bond Index (control)	.SBWES

cash distributed to LPs at the end of the quarter from the cumulative cash distributed to LPs at the beginning of the quarter.

Lastly, all these quarterly percentage changes are combined to form the unlisted infrastructure index with a starting value of 100 from the fourth quarter of 2007.

In addition to the infrastructure data indices, three other different asset classes have been collected to not only enable comparison between the performance of infrastructure in relation to other more traditional asset classes, but also to evaluate the significance of infrastructure in a traditional institutional portfolio. The three non-infrastructure asset classes are Stocks, Real Estate and Government Bonds. An overview of the European Sector and Sub-sector data and United Kingdom data along with the control data for each analysis is shown in Table 3.1, Table 3.2 and Table 3.3 respectively. And lastly, risk-free monthly and weekly returns from the same periods have been collected from the Kenneth R. French Data Library: the risk-free assets consist of monthly and weekly Treasury bills.

Table 3.2: Overview of selected indexes for European Sub-Sector analysis

Name	Ticker
Thomson Reuters EU Marine Port Service Index	.TRXFLDEUPUPORT
UBS EU Airport Index	.UDATER
UBS EU Toll Roads Index	.UTOLWDE
Thomson Reuters EU Fossil Fuels Energy Index	.TRXFLDEUPUE1
EU Renewable Index (Societe Generale)	.ERIXP
Thomson Reuters EU Natural Gas Index	.TRXFLDEUPUGASU
EU Total Market Electricity (STOXX)	.STOXX

Table 3.3: Overview of selected indexes for United Kingdom analysis

Name	Ticker
Thomson Reuters UK Energy Index	.TRXFLDGBPE1
Thomson Reuters UK Telecommunication Services Index	.TRXFLDGBPCOM
Thomson Reuters UK Utilities Index	.TXFLDEXPUUTL
Thomson Reuters UK Transport Infrastructure Index	.TRXFLDGBP14
FTSE 350 Index	.FTLC
Thomson Reuters UK Real Estate Index	.TRXFLDGBPF4
United Kingdom Government Bond Index, 3-5 years	.SBUK35U
FTSE All share Index (control)	FTAS
FTSE 350 Real Estate (control)	.FTUB8600
UK Government Bond Index (control)	.SBUKU

3.2 European data

Summary Statistics of European Sector and Sub-sector data

The aim of this section is to examine the descriptive statistics of the data in order to identify the structure of the data and check if it is in line with our expectations and assumptions of the financial returns of infrastructure. Descriptive statistics summarise the main features and characteristics of a data set quantitatively, providing us with important information for understanding how to proceed with our analysis.

This section summarises the descriptive statistics of the European sector data (Table 3.4) and their controls (Table 3.5); the Energy sub-sector data (Table 3.6); the

Transport sub-sector data along with the traditional assets used to compare both the Energy and Transport sub-sectors (Table 3.7); and lastly, the extended European sector data along with the unlisted infrastructure data is given in (Table 3.8). The number of observations for each data are shown in each table. It should be mention that the number of observations of our datasets are large enough to guarantee the robustness of the analyses that will follow in the subsequent chapters. The dataset and the number of observation used is one of the largest used in the infrastructure literature so far. The tables confirm that the data selected represents the financial characteristics of listed infrastructure. As mentioned in Chapter 2, the financial returns of infrastructure are not expected to follow a normal distribution (Bianchi et al., 2014, Dechant and Finkenzeller, 2012, Dechant et al., 2010); and indeed the non-Gaussianity of the data is identified by the negative skewness and high kurtosis. Negative skewness and excess kurtosis were encountered in other research using listed infrastructure, e.g., (Bird et al., 2014, Sawant, 2010b). This also holds true when looking at the Energy and Transport sub-sector data separately from the Telecommunication sector in Table 3.8.

Table 3.4 to Table 3.8 also confirm the heterogeneity among infrastructure sectors. For example, some sectors such as telecom are seen to illustrate lower levels of skewness than energy, utilities and transport. Similarly, excess kurtosis is different among infrastructure sectors. When we look into sub-sector data, the heterogeneity of the infrastructure assets is more clearly observable. In effect, one can conclude that the degree of non-Gaussianity differs between infrastructure sectors and sub-sectors and it affects some much more than others.

When we examine the traditional assets, stocks and real estate, we observe that they show higher skewness than infrastructure sectors, while government bonds are seen to be approximately symmetrical. The control data shows similar mean and standard deviation to the indices used in the main analysis. Furthermore, the control data shows the same level of skewness and kurtosis for real estate. However, for stocks the control data shows a less skewed distribution and less kurtosis and for government bonds, the control data shows a more skewed distribution and higher kurtosis than the index used in the main analysis.

Table 3.4: Descriptive Statistics for the EU Sector sample

	Energy	**Telecom**	**Utilities**	**Transport**	**Stocks**	**Real Estate**	**Bonds**
Mean	0.004	0.004	0.005	0.008	0.002	0.006	0.005
Standard Deviation	0.063	0.056	0.060	0.069	0.053	0.071	0.030
Min	-0.198	-0.183	-0.215	0.216	-0.213	-0.356	-0.088
Max	0.160	0.137	0.116	0.140	0.102	0.172	0.085
Skewness	-0.425	-0.458	-0.798	-0.779	-1.273	-1.191	-0.376
Kurtosis	3.811	3.582	3.976	3.808	6.007	7.483	3.834

Start Date: 31/1/2003 , End Date: 31/12/2013 ,Frequency: Monthly, No. of Observations: 132

Table 3.5: Descriptive Statistics for the EU Control sample

	Stocks	**Real Estate**	**Bonds**
Mean	0.003	0.005	0.002
Standard Deviation	0.041	0.068	0.021
Min	-0.126	-0.345	-0.088
Max	0.114	0.163	0.069
Skewness	-0.668	-1.286	-0.774
Kurtosis	4.350	7.784	6.936

Table 3.6: Descriptive Statistics for the EU Energy Sector sample

	Fossil Fuels	**Renewable Energy**	**Natural Gas**	**Electricity**
Mean	0.0007	0.0004	0.0010	0.0013
Standard Deviation	0.0366	0.0469	0.0250	0.0273
Min	-0.2610	-0.3643	-0.2029	-0.2702
Max	0.1719	0.1961	0.1170	0.1014
Skewness	-0.8307	-1.4160	-1.0108	-2.2216
Kurtosis	10.2220	12.1978	13.3471	22.2263

Start Date: 31/1/2004 , End Date: 31/12/2013, Frequency: Weekly , No. of Observations: 523

Table 3.7: Descriptive Statistics for the EU Transport Sector sample

	Ports	**Airports**	**Toll Roads**	**Stocks**	**Real Estate**	**Bonds**
Mean	0.0021	0.0015	0.0011	0.0007	0.0008	0.0008
Standard Deviation	0.0337	0.0281	0.0301	0.0273	0.0386	0.0151
Min	-0.1923	-0.2676	-0.2278	-0.2425	-0.2370	-0.1222
Max	0.2077	0.1504	0.1268	0.1244	0.1179	0.0831
Skewness	-0.6353	-1.8405	-1.0883	-1.6292	-1.4927	-0.9670
Kurtosis	10.5880	20.8003	11.0211	16.9049	9.2964	13.0992

Start Date: 31/1/2004 , End Date: 31/12/2013, Frequency: Weekly , No. of Observations: 523

Table 3.8: Descriptive Statistics for the extended EU Sector listed sample and Unlisted Infrastructure

	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Bonds	Unlisted Infra.
Mean	0.001	0.009	0.009	0.019	0.008	0.015	0.011	0.019
Standard Deviation	0.121	0.101	0.109	0.121	0.100	0.140	0.023	0.046
Min	-0.375	-0.200	-0.266	-0.307	-0.309	-0.466	-0.048	-0.1653
Max	0.197	0.208	0.195	0.281	0.189	0.319	0.076	0.081
Skewness	-0.914	0.130	-0.672	-0.614	-1.137	-0.772	0.282	-2.441
Kurtosis	3.729	3.868	3.263	3.475	4.424	4.690	3.833	10.584

Start Date: 31/3/2003, End Date: 21/12/2015, Frequency: Quarterly, No. of Observations: 52
Start Date: 1/1/2008, End Date: 30/6/2015, Frequency: Quarterly, No. of Observations: 30

Table 3.9: Normality test for the EU Sector sample

	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Bonds
JB test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.03)	(0.04)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)
KS test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lillie test	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE
p-value	(0.27)	(0.33)	(0.09)	(0.00)	(0.00)	(0.00)	(0.04)

True: Reject null, null: Distribution is normal, Significance level: 5%

Normality test for European Sector and Sub-sector data

Table 3.9, 3.10 , 3.11 and 3.12 show three different normality tests done on the European sector and sub-sector data in order to confirm whether the data is Gaussian or not. In line with the results of previous research, and as already indicated by the descriptive statistics in Section 3.2, the normality tests indicate that the infrastructure sector data used in this thesis do not follow a normal distribution. In almost all of the three different tests done for the European sector data, the null that the infrastructure sectors follow a normal distribution is rejected. In the only cases where the null is not rejected, e.g., the Lillie test for the energy, telecom and utilities sectors, the tests are not significant. Non-normality is also confirmed in the sub-sector data.

Table 3.10: Normality test for the Energy Sector sample

	Fossil Fuels	**Renewable Energy**	**Natural Gas**	**Electricity**
JB test	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)
KS test	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)
Lillie test	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)

True: Reject null , null: Distribution is normal, Significance level: 5%

Table 3.11: Normality test for the Transport Sector sample

	Ports	**Airports**	**Toll Roads**	**Stocks**	**Real Estate**	**Bonds**
JB test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
KS test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lillie test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

True: Reject null, null: Distribution is normal, Significance level: 5%

Table 3.12: Normality test for the extended EU Sector listed sample and Unlisted Infrastructure

	Energy	**Telecom**	**Utilities**	**Transport**	**Stocks**	**Real Estate**	**Bonds**	**Unlisted Infra.**
JB test	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE
p-value	(0.02)	(0.50)	(0.07)	(0.08)	(0.01)	(0.01)	(0.24)	(0.00)
KS test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lillie test	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	TRUE
p-value	(0.17)	(0.08)	(0.29)	(0.02)	(0.00)	(0.05)	(0.12)	(0.00)

True: Reject null, null: Distribution is normal, Significance level: 5%

3.2.1 United Kingdom data

Descriptive Statistics and normality tests for UK data

The descriptive statistics of the UK data presented in Table 3.13 illustrate, similar with the European Statistics, that the UK infrastructure sectors exhibit high kurtosis and negative skewness. The heterogeneity among infrastructure sectors is illustrated in the UK data as well. Traditional assets, stocks and real estate also show high kurtosis and negative skewness, while government bonds here are characterised by low levels of negative skewness and low excess kurtosis. The UK control data presented in Table 3.14 is in line with the indices used in the

Table 3.13: Descriptive Statistics for the United Kingdom Sector sample

	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Bonds
Mean	0.003	0.006	0.004	0.007	0.005	0.003	0.004
Standard Deviation	0.057	0.050	0.069	0.068	0.041	0.066	0.025
Min	-0.216	-0.129	-0.222	-0.284	-0.144	-0.253	-0.079
Max	0.147	0.101	0.136	0.151	0.088	0.184	0.083
Skewness	-0.657	-0.378	-0.719	-1.309	-0.850	-0.889	-0.154
Kurtosis	4.625	2.681	3.572	6.453	4.414	5.627	3.804

Start Date: 31/1/2003, End Date: 31/12/2013, Frequency: Monthly , No. of Observations: 132

Table 3.14: Descriptive Statistics for the United Kingdom Controls sample

	Stocks	Real Estate	Bonds
Mean	0.005	0.003	0.004
Standard Deviation	0.041	0.065	0.028
Min	-0.144	-0.243	-0.095
Max	0.091	0.210	0.074
Skewness	-0.856	-0.713	-0.300
Kurtosis	4.464	5.430	3.734

Table 3.15: Normality test for United Kingdom data

	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Bonds
JB test	TRUE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE
p-value	(0.00)	(0.11)	(0.01)	(0.00)	(0.00)	(0.00)	(0.09)
KS test	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
p-value	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lillie test	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE
p-value	(0.12)	(0.03)	(0.01)	(0.00)	(0.00)	(0.00)	(0.5)

True: Reject null, null: Distribution is normal, Significance level: 5%

main analysis. As already indicated in the descriptive statistics Table 3.13 and Table 3.14 show that the data is not Gaussian. This is confirmed in all three normality tests done, which are presented in Table 3.15.

3.3 Methodology

In this section a brief discussion is dedicated to optimisation methods that will lead us to the detailed descriptions of the main methodologies followed in Chapters 5 to 8. The two main objectives of Chapters 5 to 8 are to compare different infrastructure sectors and sub-sectors and to illustrate the effect of investing in infrastructure within a traditional institutional portfolio.

Portfolio Analysis

Understanding and quantifying risk at the total portfolio level is important for banks, financial institutions and other institutional investors dedicated to protecting the value of their assets and being able to meet their liabilities. Sound and robust risk management can help these decision makers plan for the consequences and hedge against relevant risks in the aim to control them.

Risk assessment of financial entities not only benefits the single firm or investor, but is also advantageous for the whole economy. For instance, during the financial crisis of 2008, the banking crisis not only incurred significant effects within the financial sector but effects also profoundly impacted the real economy as well. For this reason, after the crisis, new financial regulation to guarantee the stability of financial institutions was put into force. This gave rise to the evolution of many risk management tools that attempted to understand and quantify financial risks. That is why, at present, many different risk measures are applicable at portfolio level. Against this background, and given the importance of controlling for these risks, this thesis aims to apply different forms of risk in order to assess the suitability of listed and unlisted infrastructure in a portfolio.

In a portfolio analysis a portfolio manager must identify the optimal allocation of an investor's wealth into different assets. Over the last 65 years, different methods have been developed to resolve the problem of optimal allocation. The mean-variance optimisation (MVO) was the first model developed that aimed to derive the optimal portfolio. Despite its many weaknesses, the mean-variance portfolio remains the most popular optimisation technique due to its clarity and simplicity.

3.4 Mean-Variance optimisation

The establishment of MVO has provided the foundation for Modern Portfolio Theory (MPT) which until now, has been the most applied theory in the financial world (Markowitz, 1952, 1959). Markowitz (1959) defined risk as the variance or standard deviation of returns and by using mean returns, variances and covariances among asset classes, he established the theory of diversification. For Markowitz, the portfolio risk should measure the effect among different assets. In MVO, this effect is captured either through calculating the covariance or the correlation among different asset classes.

In Markowitz (1959), the portfolio returns are calculated as:

$$Return_{portfolio} = \sum_{i=1}^{n} x_i * ri \tag{3.2}$$

where, x_i represents the ith/inidividual security or asset in the portfolio and r_i the return of the individual security. Equation 3.2 will be used to calculate the returns of the portfolio in all the optimisations that will be done in this thesis.

In the MVO the variance of the portfolio is calculated as:

$$Variance_{portfolio} = \sum_{i=1}^{n} x_i^2 * SD_i^2 + 2\sum_{j=1}^{n}\sum_{i>1}^{n} x_i x_j r_{ij} SD_i SD_j \tag{3.3}$$

where $i \neq j$, $SD_p = \sqrt{Variance_{portfolio}}$, r_{ij} is the correlation coefficient between the ith and jth variables and SD_i is the Standard Deviation of the ith variable.

The MVO is used to calculate either the maximum expected return that can be achieved for a specific risk, or the lowest risk given a specific return. These are called efficient portfolios and they can all be represented on an efficient frontier that trades off the expected returns and risk of a portfolio. The points on the efficient frontier represent only optimal portfolios where a higher return cannot be achieved for a given risk (or a lower risk cannot be achieved for a given return). Merton (1972) identified the shape of the efficient frontier to be hyperbolic, enclosing all the inefficient portfolios inside of it. The efficient portfolio that minimises risk is called the minimum variance portfolio. Portfolio optimisation of financial analysis determines which assets are optimal to be included in the portfolio and in what proportion. By re-optimising an existing portfolio one can achieve an outward shift in the portfolio frontier which implies an increase in efficiency as more returns can be achieve for the same amount of risk.

This is the so-called MVO that revolutionised the financial world and set the stage for asset management and financial portfolio optimisation techniques. By adding lending or borrowing at the risk-free rate, it is possible to invest a proportion in an efficient portfolio and a proportion to the risk-free asset. The introduction of the risk-free asset creates a new opportunity set that it is tangent to the efficient frontier, known as the capital market line (CML). The CML creates dominant efficient portfolios, because investing both in an efficient portfolio and a risk- free asset can achieve higher levels of returns at the same level of risk (Sharpe, 1964). This finding has provided the foundation for pricing capital assets, the CAPM.

The MVO relies on the first two moments of the probability distribution of returns and the inter-dependence among assets, which is measured by Pearson's correlation coefficient. There are a number of scholars who have outlined the weaknesses of MVO, and this will be our focus in the next section. However, despite these weaknesses, it is worth mentioning that MVO still maintains popularity among practitioners, as no other allocation method to date has outperformed the simplicity and clarity presented by the MVO.

3.5 Criticisms of Mean-Variance optimisation

- **Normality of Returns**

  MVO analysis is concerned only with the first two moments of the asset's probability distribution of returns. However, if the asset's distribution or returns is skewed, portfolio analysis under the MVO will ignore this when considering the desirability of the security. This is of particular concern, for instance, if a security has a skewed to the left distribution, where a negative event is the most likely outcome (Francis and Kim, 2013). Markowitz argued that ignoring the third or fourth model of the asset's distribution is not a flaw in the model because empirical evidence shows that historic distribution of returns are approximately normally distributed. When asset returns are normal, in other words, when asset returns are symmetrical around the mean, it is not necessary to consider further moments such as skewness or kurtosis. However, the normality assumption does not hold true across all securities and asset classes. There are asset returns that showed skewness and/or excess kurtosis, indicating that a normal distribution is not a representative distribution for the asset class (Blattberg and Gonedes, 1974, Cont, 2001, Cootner, 1964, Fama, 1968, Kendall and Hill, 1953, Kon, 1984, Lintner, 1972, Lo and MacKinlay, 1988, Longin, 1996, Loretan and Phillips, 1994, Mandelbrot, 1963). If the data is not normally distributed, then a symmetrical risk measure will fail to capture the whole distribution of asset returns. This holds particularly true for alternative assets such as infrastructure, where the existence of small data sets makes it even harder to prove normality (Krokhmal et al., 2002). For this reason, it is important to check the optimisation of infrastructure assets by also considering other optimisation techniques that do not require a specific statistical distribution.

- **Investors' Preferences and Variance as a risk-measure**
  Markowitz modelled investor preferences by the mean and variance of an asset's distribution. In Levy and Markowitz (1979) the MVO was linked to expected utility, where the authors showed that investing in an efficient portfolio is the same as maximising expected utility. The MVO implies negative marginal utility of wealth, which violates rational investor behaviour assumptions, as it implies that additional wealth is unwanted (Francis and Kim, 2013). Furthermore, it implies increasing absolute risk aversion, which means that as investors wealth increases, they will become more risk averse. This is also an unrealistic assumption and it does not represent the actual preferences of investors. Furthermore, the variance measure implies that investors are indifferent when it comes to negative profits and large profits, which is once again unrealistic, because while investors will not favour small or negative profits, they will of course, welcome large returns. In contrast

to variance, which is symmetrical, investor preference is not symmetrical around the mean. Actually, investor preferences have shown loss aversion, which implies that investors are more sensitive to losses than gains.

- **Single period model**
  The last weakness of the MVO is that it uses a single period moment; in other words, it optimises the allocation of assets for an investment horizon. Pension funds and other fund managers make investments for long periods where probability density functions are expected to change within the investment period. This factor was observed by Markowitz himself because probability density functions are subject to change with time, illustrating the weaknesses of using a deterministic estimate of the mean, variance and covariance matrix.

3.6 Advances of Mean-Variance optimisation

Many researchers have set out to improve the MVO but did not substantially question variance as a measure of risk, such as Fama and French (1992), Hwang and Satchell (1999), Jean (1971, 1973), Konno and Suzuki (1995), Konno and Yamazaki (1991), Liu et al. (2003), Sharpe (1963, 1967). The developments discussed by the authors listed above are nevertheless still subject to similar kinds of criticism as the MVO. However, other measures have been introduced which are not extensions of the MVO, thereby implying that they do not require assets' returns to be normal or investors' utility functions to be quadratic (Elton and Gruber, 1975, Estrada, 2007, 2008*a*,*b*, Merton, 1971, Young and Trent, 1969).

Furthermore, after the recent financial crisis of 2008, some of the traditional economic models came under fierce scrutiny. Therefore, in the aim to prevent such crises from recurring, relevant economic models were tested for their accuracy and suitability. For this reason, recent developments include an increased focus in disciplines that go beyond traditional finance, such as behaviour economics, prospect theory (Kahneman and Tversky, 1979) and new risk management techniques. An example of models developed in response to the crisis include Garleanu (2009) who developed an optimisation problem that also addresses liquidity risks, something that proved to be of particular significance during the crisis.

Practitioners of financial risk management have turned their attention to fairly new developments in the field that address the topic of tail risks of distributions. After many (smaller) financial failures in the early 1990s, institutions and regulators were prompted to establish advanced risk-management measures in order to handle portfolio risks (Francis and Kim, 2013); these included the Value-at-Risk (Jorion, 2007). Value-at-Risk (VaR) is the maximum expected loss that will not be exceeded under a certain probability level, such as 95% or 99%. VaR gained great popularity, not only among practitioners but also among regulators. For instance, the Basel Committee also use VaR as a standard regulatory measure; VaR has also been adopted by the rules of Solvency II regulation which are applicable to institutional investors (e.g., insurance firms and pension funds). For reasons that we will explore in detail later in this Chapter, VaR is not an ideal risk measure to be used in portfolio optimisation. Therefore, VaR was extended, giving rise to a popular extension known as the Conditional Value at Risk (CVaR): the expected loss above VaR (Rockafellar and Uryasev, 2000, Uryasev, 2000). Another risk-management measure is called the Conditional Drawdown-at-Risk (CDaR), an important downside risk measure in that it minimises drawdowns. Minimising drawdowns are significant in relation to portfolio performance because they indicate the consecutive loss(es) of the portfolio (Chekhlov et al., 2000). CVaR and CDaR measures are also known as downside risk measures because they are concerned with losses at the left tail of the distribution.

3.6.1 Optimising a portfolio that invests in infrastructure

Despite its disadvantages, the MVO has revolutionised the financial studies and is to date the most commonly used optimisation method; it is also the benchmark for other optimisation methods. For this reason, the MVO is the standard optimisation method we will use in the present thesis, as well as in the examination of listed and unlisted infrastructure in the portfolio context. However, in the optimisation of listed infrastructure sectors and sub-sectors is also examined under other risk frameworks: the Mean-Absolute Deviation (MAD), the Mean-Conditional Value at Risk (M-CVaR) and the Mean-Conditional Drawdown at Risk (M-CDaR).

The Mean-Absolute Deviation (MAD) optimisation is chosen for its ability to be directly compared to the MVO, it is a very popular alternative to Markowitz, and it maintains certain advantages over Markowitz, i.e. producing optimal portfolios that are second order stochastically dominant as well as capable of dealing better with noise in the underlying data. This factor is essential to our analyses, given that the data for infrastructure is too noisy to enable robust estimations of its statistical properties. Furthermore, it is optimised using linear programming, similar to our other two optimisations, Mean- Conditional Value at Risk (M-CVaR) and Mean-Conditional Drawdown at Risk (M-CDaR).

The most important factor in choosing the aforementioned two optimisations is that neither M-CVaR nor M-CDaR depend on any assumptions about the underlying asset returns distribution. As seen from other scholars in the literature review, and as this chapter proves, infrastructure returns exhibit skewness and high kurtosis, which is an indicator of large fat tails and thus non-normal returns. The CVaR approach is also selected due to the increasing popularity of the VaR measure as the standard way to report potential losses in all corporations along with its application in regulatory frameworks. For instance, the Basel III and Solvency II regulation applicable to banks and institutional investors, respectively, have used VaR as the standard regulatory measure.

Whereas Conditional Value at Risk (CVaR) is built on the idea of VaR, but it is more appropriate to use in optimisations, as we will demonstrate further on in this chapter. We suggest that CVaR could also gain in popularity among practitioners since VaR is already in wide use.

Lastly, we have chosen the Drawdown measure because Drawdowns are quite important to investors but also to fund managers and other institutions (Chekhlov et al., 2000). As Chekhlov et al. (2000) has convincingly argued, investors are particularly concerned with losing capital and they will replace their fund managers if their accounts illustrate long periods of drawdowns. Furthermore, from the fund manager's point of view that their core business depends on their clients' accounts, losing this money would determine the end of their business, even in cases of long-term returns, which are attractive but can be realised only in the long- term. Similarly, a trader in an investment bank is not permitted to illustrate a drawdown for more than a year.

Portfolio Returns

As previously mentioned, in all of the optimisations used in later chapters, the portfolio's return is calculated as

$$Return_{portfolio} = \sum_{i=1}^{n} x_i * r_i \tag{3.4}$$

where, r_i represents the return of different listed infrastructure sectors or sub-sectors, unlisted infrastructure, and the returns of the three traditional assets. x_i represents the weight invested in each asset. Short-sales are not allowed in the portfolio and all the weights of the asset should sum to 1. The fact that there is a limit in the capital available does not have any effect in the statistical analysis as the aim of the analysis is to determine how this capital will be allocated into the different assets.

In addition to the analyses and critique of Markowitz, a number of other optimisation techniques are used to investigate the impacts of different infrastructure sectors and sub-sectors on an institutional portfolio when it is evaluated under different risks. The remainder of this chapter explains in detail the three optimisation techniques used in this thesis other than the MVO.

3.6.2 Mean-Absolute Deviation framework

Konno and Yamazaki (1991) introduced the Mean-Absolute Deviation (MAD) as a viable alternative to the Markowitz model. The Mean-Absolute deviation is defined as

$$MAD = E[|\sum_{i=1}^{n}(x_i r_i) - E\sum_{i=1}^{n}(x_i r_i)|]. \tag{3.5}$$

where r_i is the random rate of return for security i and x_i is the weight invested in security i. In this thesis rather than simulated data, we use historical returns of different listed infrastructure sectors or sub-sectors as well as historical returns of traditional assets. Hence, r_i represents the historical returns of each asset, while x_i is the weight invested in each.

The MAD equation can be re-written as

$$\frac{1}{J}\sum_{j=1}^{J}|\sum_{i=1}^{n}(r_{ij} - \mu_i)x_i| \tag{3.6}$$

where r_{ij} is the historical return of each asset in the jth period; j represents the historical frequency of the data, for example in the European and United Kingdom sector analyses where monthly returns are collected $j = 1, ..., 132$; meanwhile, in the European sub-sector analyses where weekly returns are collected $j = 1, ..., 523$ and μ_i is equal to $\frac{1}{J}\sum_{j=1}^{J} r_{ij}$ i.e. the average return of the portfolio.

Konno (1990) proved that for portfolio returns that are multivariate normally distributed, $MAD = \sqrt{\frac{2}{\pi}}\sigma$. The implication here is that for multivariate normally distributed random variables, minimising MAD is equivalent to minimising variance.

One of the advantages of MAD is that it can be easily deduced to a linear optimisation using additional variables it is simpler to compute the optimal portfolio than with the standard Markowitz approach (Cornuejols, 2006).

$$
\begin{aligned}
\min \sum_{j=1}^{J} u_j^+ + u_j^- \\
\text{s.t.} \quad & u_j^+ - u_j^- = \frac{1}{J}\sum_{j=1}^{J} |\sum_{i=1}^{n}(r_{ij} - \mu_i)x_i|, \quad && j = 1, ..., J \\
& u_j^{+-} \geq 0, && j = 1, ..., J \\
& \sum_{i=1}^{n} x_i = 1
\end{aligned}
\tag{3.7}
$$

Furthermore, MAD deals better with noisy data, as in the variance (Markowitz) the distances from the mean are squared, so large deviations are weighted more. In MAD, as the absolute value is taken, outliers become less relevant. Another important advantage of MAD over the MVO is that portfolios generated under MAD are never stochastically dominant while MVO produces second-order stochastically dominant optimal portfolios. Portfolios are second-order stochastically dominated over dominant portfolios if their outcomes are certain and more predictable (Cornuejols, 2006). Concave utility functions (risk-averse) prefer second-order stochastically dominated portfolios to dominant portfolios.

3.6.3 Conditional Value-at-Risk

Financial institutions looked for alternative measures to quantify and manage their risks. One alternative widely used measure of risk is Value-at- Risk (VaR) that was developed by J.P Morgan in the late 1980s (Jorion, 2007). The VaR presents the maximum loss that will be endured with a given probability level for a specified period. $VaR_a(X)$ for portfolio X means that with a $(1-\alpha)$ probability, the portfolio loss will not exceed this level (Duffie and Pan, 1997, Jorion, 2007). In this thesis, α is always 95%.

The $VaR_a(X)$ is defined as:

$$VaR_a(X) = \min\{\gamma : P(X \geq \gamma) \leq 1 - \alpha\} \tag{3.8}$$

Although VaR is commonly used in the financial industry and it is also widely demanded by regulation, it has received a lot of criticism from academics. VaR has many shortcomings both in relation to its adequacy as a risk management measure as well as it's suitability in optimisation techniques. First of all, VaR fails to consider losses beyond the VaR measure, which makes the unrealistic assumption that an investor would be indifferent between losses that exceed VaR by a lot and losses that just exceed VaR by a small amount. Furthermore, VaR is not sub-additive. This means that the VaR of two instruments could be larger than the VaR of one instrument (Artzner et al., 1999). This does not respect the diversification property of portfolios where a diversified portfolio is always less risky than a concentrated portfolio. The combined risk of investing in two assets should never exceed the sum of the individual risk of the two assets. Another weakness of VaR is that it assumes a normal distribution of the underlying data (Chambers et al., 2014, Uryasev, 2000). Last but not least, the VaR has many mathematical drawbacks that make it quite hard to use in optimisation. For instance, it is non-convex and its optimisation leads to many multi minima. Convexity is a key property in optimisations as it ensures that a local minimum will be the global minimum.

For all these criticisms, Rockafellar and Uryaser (2000, 2002) came up with an alternative different risk measure, which is a modification to the VaR the Conditional Value-at-Risk (CVaR) that preserves all the good qualities of VaR and eliminates all the drawbacks. In the financial literature CVaR is often called as the Mean Expected Loss, Mean Shortfall or Tail VaR as CVaR calculates the average of the worst $(1-\alpha)$ of the loss function (Rockafellar and Uryasev, 2000, 2002). The optimisation of CVaR is a smooth convex optimisation problem that can be easily computed using linear programming techniques. In consequence, CVaR has better properties than VaR such as convexity which guarantees that a local minimum will not be different than a global minimum (Rockafellar, 1970). Furthermore, CVaR is sub-additive and a better measure of risk as it takes into account losses beyond VaR (Cornuejols, 2006).

The α-Conditional Value-at-Risk for a portfolio of $x \in \mathbb{X}$, is defined as:

$$CVaR_a(X) = \frac{1}{1-\alpha} \int_{f(x,y) \geq Var_\alpha(x)} f(x,y)p(y)dy. \tag{3.9}$$

For a discrete probability distribution (where the random return y_i occurs with probability p_j, for $j = 1, ..., n$), the equation 3.9 will become

$$CVaR_\alpha(x) = \frac{1}{1-\alpha} \sum_{j:f(x,y) \geq VaR_\alpha(x)} p(j)f(x,y_i). \tag{3.10}$$

Both the CVaR and the VaR measure are used in Chapter 6 in order to compare the performance of the optimal portfolios given by the four different optimisation techniques used in this thesis.

The density function $p(y)$ is not easy to calculate therefore, in this thesis historical values for y_j for $j = 1, ..., J$ are used. In the European and United Kingdom sector analysis, j represents monthly historical returns hence, $j = 1, ..., 132$, while in the sub-sector analysis weekly returns are used hence, $j = 1, ..., 523$. In this case the $CVaR_a(X)$ will be discrete rather than continuous and the loss function is calculated by the negative of the portfolio returns. For this reason, in this thesis since the aim is to compare different optimisation techniques, rather than expressing CVaR in monetary terms, the loss function will be defined as the negative of the portfolio returns and it will be expressed in percentage terms to be consistent with the other optimisations used in this thesis.

For a detail analysis of how CVaR is minimised the reader is referred to Cornuejols (2006), Rockafellar and Uryasev (2000, 2002). As introduced in Rockafellar and Uryasev (2000), the following function is used:

$$\widetilde{F}_\alpha(x,\gamma) = \gamma + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J}(-\sum_{i=1}^{m} y_{ij}x_i - \gamma)^+. \tag{3.11}$$

where y_{ij} represents the ith infrastructure sector or sub-sector as well as the three traditional assets used, in the jth scenario, which is either the monthly or weekly returns respectively.

To this extent, the optimisation objective becomes:

$$\min_{x\in\mathbb{X},\gamma} \gamma + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J}(-\sum_{i=1}^{m} y_{ij}x_i - \gamma)^+. \tag{3.12}$$

To solve this, the auxiliary variable z_j is introduced that is subject to the following constraints $z_j \geq -\sum\limits_{j=1}^{m} y_{ij}x_i - \gamma$ and $z(s) \geq 0$.

In effect, the optimisation problem becomes:

$$\begin{aligned}
&\min_{x,z,\gamma} \gamma + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J} z_j \\
&\qquad\qquad \text{s.t.} \quad z_j \geq 0, \qquad\qquad\qquad\qquad j = 1, ..., J. \\
&\qquad\qquad\qquad\quad z_j \geq -(\sum_{i=1}^{m} y_{ij}x_i) - \gamma), \quad j = 1, ..., J \\
&\qquad\qquad\qquad\quad x \in \mathbb{X}.
\end{aligned} \tag{3.13}$$

One very important property of the formulation in 3.13 is that y does not depend on a specific distribution, hence, the optimisation in 3.13 works for non normal distributions as well (Rockafellar and Uryasev, 2000). As seen in the normality tests done, the data exhibits non-normal returns thus, using CVaR is an adequate optimisation given the non-normal distribution of the data.

3.6.4 Conditional Drawdown-at-Risk

Another risk management technique that this thesis will focus on is the Conditional Drawdown-at-Risk (CDaR). CDaR is another downside risk measure which is concerned with the consecutive loss of capital. Chekhlov (2000) defined drawdowns as the drop in the portfolio value compared to its previous peak (Chekhlov et al., 2000).

The Drawdown function at time t is the difference of the maximum of the function $w(x,t)$ over the sample path previous to time t and the value of this function at time t (Chekhlov et al., 2000):

$$D(x,t) = \max_{0 \le \tau \le t} \{w(x,\tau)\} - w(x,t). \tag{3.14}$$

where x is the vector of the portfolio weights of the m assets in the portfolio such that $x = x_1, ...x_m$ and $w(x,t)$ is the uncompounded portfolio value at time t.

Drawdowns are also considered a good measure of downside risk because not only do they show the amount lost, but they also indicate the duration of the losses. Drawdowns can be measured per time for a specified sample path and are usually illustrated on a graph. However, only one measure can be used across the whole path. In this thesis, two such measures are used to evaluate the performance of the optimal portfolios in Chapter 6. One such measure is the maximum drawdown, which for the interval [0,T] is defined as:

$$MaxDD = \max_{0 \le t \le T} \{D(x,t)\} \tag{3.15}$$

or the Average Drawdown,

$$AverDD = \frac{1}{T} \int_0^T D(x,t)dt \tag{3.16}$$

If we were to minimise only the maximum drawdown, uncertainty would arise because a specific extreme event may not repeat in the future and minimising average drawdown can hide large drawdowns. To resolve this problem, Cheklhlov (2000) suggests minimising another drawdown measure the Conditional Value at Risk (CDaR). However, Average Drawdown and Maximum Drawdown are nevertheless important for both institutional investors as well as fund managers they are used in the evaluation of the optimal portfolios in Chapter 6.

Minimising CDaR

Like the CVaR approach, Conditional Drawdown-at-Risk for a confidence level of 95% can represent an average of the highest 5% drawdowns. In effect, for a given parameter α, a-CDaR is equal to the mean of the worst $(1-a)*100\%$ drawdowns.

The CDaR function is therefore calculated as:

$$CDaR(x) = \frac{1}{(1-\alpha)J}\int_{D(x,t)\geq\gamma_\alpha(x)} D(x,t)dt \tag{3.17}$$

where $\gamma_{\alpha(x)}$ is the threshold that is exceeded by the $(1-a)J$ drawdowns.

Since for the analyses of this thesis historical monthly or weekly returns are obtained, the uncompounded portfolio value is represented by a district distribution such that the uncompounded portfolio value at time j is computed by:

$$w_j(x) = \sum_{i=1}^{m}(1+\sum_{s=1}^{j} y_{is})x_i \tag{3.18}$$

where y_{ij} is the rate of return of the ith infrastructure sector or sub-sectors in jth trading period. Specifically, for the European and United Kingdom sector analyses $s = 1, ..., 132$ while for the European sub-sector analysis $s = 1, ..., 523$ and x_i is the weight of each infrastructure sector or sub-sector in the portfolio. It's worth noting here that the sample path of the portfolio is obtained from historical or simulated returns (Krokhmal et al., 2002). In the analyses of this thesis historical monthly and weekly returns are used.

To this extent, the drawdown function of equation 3.14 is:

$$\widetilde{f}(x, y_j) = \max_{1\leq k\leq j}\{\sum_{i=1}^{m}(\sum_{s=1}^{k} y_{is})x_i\} - \sum_{i=1}^{m}(\sum_{s=1}^{j} y_{is})x_i \tag{3.19}$$

where, $\max_{1\leq k\leq j}\{\sum_{i=1}^{m}(\sum_{s=1}^{k} y_{is})x_i\}$ is the highest point achieved up to k where k represents all the time before period j. For example, if in the European sector analysis j represents the 12-th month of our data sample then $\max_{1\leq k\leq j}\{\sum_{i=1}^{m}(\sum_{s=1}^{k} y_{is})x_i\}$ will be the maximum value achieved across the whole first year of our data.

Similar to Rockafellar and Uryasev (2000) the a-CDaR function for the number of scenarios J is minimised by

$$\min_{\gamma} \gamma + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J}\max[0, \max_{1\leq k\leq j}\{\sum_{i=1}^{m}(\sum_{s=1}^{k} y_{is})x_i\} - \sum_{i=1}^{m}(\sum_{s=1}^{J} y_{is})x_i - \gamma] \tag{3.20}$$

Equation 3.20 is reduced to linear programming similar to the CVaR function.

$$\min_{x,z,\gamma} \gamma + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J} z_j$$

$$\begin{aligned}
\text{s.t.}\quad & z_j \geq u_j - \sum_{i=1}^{m}[\sum_{s=1}^{j} y_{is}]x_i - \gamma, \quad && j = 1, ..., J. \\
& z_j \geq 0, j = 1, ..., J \\
& u_k \geq [\sum_{i=1}^{m}[\sum_{s=1}^{k} y_{is}]x_i], && k = 1, ..., J \\
& u_k \geq u_{k-1}, && k = 1, ...J \\
& x \in \mathbb{X}.
\end{aligned} \tag{3.21}$$

An important property of the CDaR optimisation is that, similar to the CVaR optimisation, it does not assume any statistical distribution which is important for this thesis since as illustrated listed infrastructure returns do not exhibit a normal distribution.

In-sample and Out-of-sample Analysis

An in-sample analysis is used where the whole sample is examined to produce the efficient frontiers of the optimal portfolios under different levels of risks. In the in-sample analysis the investor is expected to pick up any portfolio on the efficient frontier given his risk appetite. Risk averse investors tent to operate in the lower level of the frontier with high risk-averse investors picking the minimum-risk portfolio which is the first portfolio of the efficient frontier, while less risk-averse investors prefer to choose a portfolio at the upper levels of the efficient frontier as they are comfortable to accept more risk for higher returns.

Apart from the in-sample analysis, in this thesis an out-of-sample analysis is also performed in Chapter 6 and Chapter 8. The out-of-sample analysis rebalances the portfolio every quarter which enables the comparison among the different trading strategies as well as indicating to which infrastructure sectors and sub-sectors is optimal to invest. Re-balancing a portfolio is important as it enables the investor to maintain its tolerance level of risk and investment strategy.

3.7 Conclusion

A large part of this thesis is dedicated to the examination of different infrastructure sectors and sub-sectors within a portfolio. While the optimality of investing in infrastructure is well-argued, to this day research to which infrastructure sectors investors should focus and the best way to construct a portfolio of infrastructure investments is still at early stages.

This chapter is important in illustrating the heterogeneity of each infrastructure sector and sub-sector which is something that will be further examined in the following chapters. The aim is to identify the heterogeneity across infrastructure sectors and sub-sectors in terms of their financial characteristics and identify what this will imply for infrastructure portfolios.

Non-normality of the data indicates that traditional portfolio techniques such as the mean-variance optimisation are inappropriate to use when constructing a portfolio that includes infrastructure data. While this was acknowledged by many researchers (Bianchi et al., 2014, Dechant et al., 2010) to date, alternative portfolio techniques have not being used in the optimisation of different infrastructure sectors and sub-sectors. As indicated in this Chapter there are optimisations that do not require a certain statistic distribution of the underling data. Therefore, in order to make the results of this analysis more robust, in addressing the objectives of this thesis two such optimisations along with two traditional optimisation techniques are used.

In the next Chapter, the reluctancy of private investors to invest in EU infrastructure will be examined.

Chapter 4

Attracting private sector participation in infrastructure investment

4.1 Introduction

In the context of the present economic downturn not only is it essential to examine infrastructure investment as a major contributor to a higher economic growth rate (Balesh, 2012) , but it is also critical to study how these investments can be organised and supported by financial mechanisms. The total amount of infrastructure investment required to sustain economic growth in OECD countries, given the temporal horizon of 2030, is expected to exceed US$50 trillion (Della Croce, 2012), and although the majority of these future investments are expected to be financed by the private sector, the level of private transport investment is still insufficient (CBI, 2012).

Private investment in infrastructure has always been part of the financial framework, but new developments for promoting private infrastructure financing have begun to flourish in the market. An investment vehicle known as Infrastructure Funds, first set up in the mid-1990s in Australia, gained acceptance in Europe and North America during the early 2000s in response to the need for an alternative asset class after the financial downturn of that period, and as a result of the availability of cheap debt (Inderst, 2009). Infrastructure began to emerge as a new asset class that could offer stable returns and better diversification benefits due to its specific investment characteristics.

Schwartz (2011), from the World Bank, has claimed that 'investing in infrastructure is the best bet to spur growth and jobs'. The latest developments of structured finance and the wide number of financial instruments available in the market gives governments several financial tools that can be tailored and fine-tuned to achieve effective results (Schwartz, 2011). However, the private sector does not actively seek to invest in infrastructure. Our objective in this chapter is to examine the underlying reasons for the cautious participation of the private sector and its tentative attitude toward this investment class. In this chapter, it is argued that adequate availability, the structure of the financial mechanisms and satisfactory regulatory conditions are key prerequisites for enabling investment and attracting private sector participation. To this end, the argument of this chapter is built through an analysis of three main questions related to the availability, structure and regulations that are germane to infrastructure investment. Several conclusions and policy recommendations for each question are reached, the most significant of which is that, in order for infrastructure investment to help some European countries 'grow out of' the financial downturn, these governments must align their objectives more closely with those of private investors.

4.2 Do the current infrastructure investment funds promote private investment?

Infrastructure usually operates under natural monopoly market conditions, thus satisfying one or more of the following characteristics: high barriers to entry, economies of scale, inelastic demand, and long-duration. These characteristics convey many attractive investment features to infrastructure assets, including secure stable cash flows, insensitivity to macroeconomic conditions and inflation hedging properties (Martin, 2010).Therefore, the ideal investors for infrastructure assets are institutional investors like pension funds. In order to guarantee the purchasing power of their resources pension funds are known to invest in long-term inflation linked assets; therefore, from this perspective, infrastructure perfectly matches pension funds' financial strategies (Ottesen, 2011).

However, from the vantage point of the private sector when investing in infrastructure, one of the most relevant risks is certainly regulatory/political risk (Bitsch et al., 2010), given that investors have little control over the outcome of the political process. This idiosyncratic risk is significant because the stability of cash flows is only guaranteed if no change occurs in the legal and regulatory conditions pertaining to a project. Therefore, as a way to overcome the drawbacks associated with direct investment, Infrastructure Funds have been designed to offer investors opportunities to invest indirectly in this asset class. The fund strategy of Infrastructure Funds is based on portfolio diversification across a range of geographies and sectors, particularly transport, water and waste, energy, and social infrastructure, and minimum exposure to idiosyncratic risk as a result. Through the development of Infrastructure Funds, infrastructure has become an increasingly important investment to private investors seeking to benefit from the low correlation with traditional asset classes, i.e. equity and bond markets, and who are also determined to reduce risk by diversifying their portfolios (Newell et al., 2011).

Since 2008, a fund strategy known as the 'fund of funds' has been developing with the aim to widen diversification benefits. The strategy involves investing in a set of infrastructure funds rather than investing directly in infrastructure projects. The advantage of the 'fund of funds' strategy is its ability to build a well-diversified portfolio that generates higher returns for the same level of risk borne by investing the same amount in an infrastructure fund (Probitas Partners, 2007). The largest example of an infrastructure 'fund of funds' is that of Macquarie infrastructure, with a target size of US$500m. Nevertheless, despite the assumption that various

Infrastructure Funds would garner immense popularity among private investors, this type of fund represents only a small fraction of the overall asset class. Costly management fees on top of a tax are the main obstacles to investment in the 'fund of funds' strategy. These costs, with their accompanying jurisdictional issues, sends a negative signal to private investors. We can therefore assert that, although infrastructure funds have witnessed some growth in recent years, the management structure of this type of funds does not yet facilitate the entrance of private investors into the infrastructure market.

Another major barrier for private investors is the estimation of the infrastructure investment profile, i.e. the calculation of the risk/return ratio. The task is cumbersome because it is contingent on the underlying project, the industry sector, and above all, on a project's stage of development. In this context, since brownfields (secondary infrastructure) are already in operation (e.g., toll roads), this type of investment is considered to be the safest with the lowest risk/return ratio (CSAM, 2010). Conversely, greenfield investments (primary infrastructure) are assigned the highest risk/return ratio (Inderst, 2009) as they are thought to be the most risky. Given that greenfield investments have not yet been built and thus do not generate constant current income, greenfields carry both construction risks and operating risks.

The extent to which an infrastructure fund is exposed to each risk depends on the structure of the fund and how the manager addresses risk, but it is important to mention that pension fund managers do not have all the requisite knowledge to make these assessments (Della Croce, 2012). According to Inderst (2010), infrastructure risk analysis involves more than just the appraisal of traditional volatility statistics. Pension funds and their advisers must be able to calculate specific risks associated with infrastructure investments such as, for example, political risk. However, according to Della Croce (2012), information asymmetry, lack of proper data and the knowledge gap associated with the novelty of this investment vehicle make this type of estimation more problematic than for other financial assets Della Croce (2012) suggests that valid results in the form of robust risk/return ratios proving the attractiveness of infrastructure investment would be a positive step for the pension fund industry and would also benefit regulators and rating agencies.

In Europe, although many Infrastructure Funds are dedicated to European infrastructure, e.g., the Macquarie European Infrastructure Fund, funds are still insufficient compared to international levels of investment. In addition to the drawbacks mentioned above, the level of European pension fund resources needed for infrastructure investment is too low, according to Peston (Peston, 2012). For instance, taking the United Kingdom as an example, even though there are nearly 2,500 pension funds in the country, nearly half of these funds are managing less than £5 million, and only 190 pension funds have assets exceeding £1 billion (Della Croce, 2012). In contrast, in North America and Canada, pension funds have substantial resources to invest in infrastructure under umbrella organisations, e.g., the Ontario Teachers' Pension Plan (OTPP), the largest investment group in Canada. As of December 2012, OTPP assets were valued at US$104.7 billion, of which $7.7 billion was allocated to infrastructure. Whereas one of the most active UK pension funds in infrastructure investment, the London Pension Fund Authority (LPFA), in July 2010 had assets worth only £4.0 billion, with infrastructure investments of just 5% (Della Croce, 2012).

Another investment vehicle known as Sovereign Wealth Funds does not seem to have received much attention. In fact, it is worth mentioning that some European countries do not even have Sovereign Wealth Funds. As observed by Armistead (2012), the establishment of a Sovereign Wealth Fund would provide guarantees for pension funds through a government commitment to infrastructure investment, and in so doing, reduce idiosyncratic political risk. Research conducted by PWC (2011) has verified that the establishment of a Sovereign Wealth Fund improves transparency in a country, thereby mitigating the political risk and improving entry conditions for private investors. In a comparison study, it was shown that countries with sovereign funds have a higher proportion of infrastructure investment to GDP. For instance, France developed a Sovereign Wealth Fund in 2008, known as the Strategic Investment Fund, in order to invest extensively in infrastructure (Bennhold, 2008). One year later, comparative data provided by (Bance

D'Italia, 2012) confirmed that France had a proportion of infrastructure to GDP of 4%, while the UK had invested only 2% of its GDP in infrastructure. This section concludes with the observation that general and country-specific problems still hinder the entrance of the private sector in infrastructure investments. We discuss the problems, limitations and advantages of the structure of Infrastructure funds in detail in the next section.

4.3 Is the structure of the funds fit for purpose?

Different infrastructure funds have evolved to satisfy the needs of investors and also to match the several maturity structures of various investments. The Barclays infrastructure fund is one such example, however, to date none of the structures meets the complete criteria for pension funds. As mentioned above, pension funds seek vehicles that offer long-term stable inflation-linked returns (Public Accounts Committee, 2013). Keeping this in mind, three main structures are presently in use: private equity, hybrid and open-ended structures.

4.3.1 Private-equity funds

The private equity fund is the most common infrastructure fund vehicle. In this fund, the manager obtains money from investors and uses it to buy a stake in a private company with the intention to increase the stake's value by improving the financial performance of the company. These funds charge a management fee as well as carried interest. The management fee covers the expenses incurred from managing the fund, and the carried interest is compensation for the fund managers who receive a share of the annual profits as incentive for improving the performance of the fund. The structure of this type of fund is illiquid with a general duration of 10-12 years. One could argue, however, that such duration is inappropriate for infrastructure investments. The chief executive of the Pension Protection Fund, Alan Rubenstein, observed that the 'money is there, but structure ins't' (Infrastructure Investor, 2012). Rubenstein maintained that the use of private equity is unsuitable for infrastructure funding and he criticised the duration of these funds as too short to satisfy the needs of pension funds, where the life-time of their liabilities is much longer, and also as too short to enable inflation hedging. As discussed earlier, although the investment span of infrastructure assets can perfectly match the duration of pension fund liabilities, private equity funds are often structured such that their temporal horizons do not coincide as they should with the investment horizon of infrastructure assets (Ottesen, 2011).

Furthermore, infrastructure funds usually achieve lower returns than private equity and then must also pay fees structured as in private equity; this is not attractive to investors (Probitas Partners, 2007). Another valid criticism is that the amount of leverage of these funds is too high, and too much leverage leads to too much risk incurred by the investor.

4.3.2 Hybrid structures

In an attempt to address the problem of the short duration of funds, hybrid structures have been developed to 'enable investors to invest across the infrastructure risk/return spectrum by aggregating investment with both shorter and longer maturities' (Probitas Partners, 2009). In these structures, greenfield investments are sold after completion of a project in order to give investors a higher return than would have been received by holding them until maturity. After the project construction phase, long-term investors such as pension funds can enter and invest in the project, thereby avoiding construction risk and benefiting from stable and secure returns. Hybrid structures nevertheless have some limitations. One of the main sticking points is the pricing of the position at the time of transfer. Since some investors want to keep their exposure and others want to liquidate their positions, hybrid structures need to develop a standard method to price investor positions at the time of transfer (Haward, 2012).

4.3.3 Open-ended structures

A third type of infrastructure fund, known as open-ended or 'evergreen', was developed in response to the illiquidity and short duration issues associated with private equity. These are designed as open-ended real estate funds and their long duration closely matches the infrastructure characteristic of brownfield investments (long-term income streams). This structure is attractive to long-term investors who want to match their long-term liabilities, but who also want the possibility of an exit option. However, the exit option for investors creates pricing issues similar to those faced in a hybrid structure. Another problem with open-ended structures is the calculation of carried interest; they are not publicly traded so any carried interest paid to the manager is calculated on the net asset value (NAV) and this calculation can vary from fund to fund (Probitas Partners, 2009).

When we look closely at infrastructure funds, it is reasonable to argue that their structure is indeed a drawback to their success. The structure of infrastructure funds should take account of, and be adaptable to, private investor needs. Despite the attraction of pension funds to infrastructure investments, the pricing issues in conjunction with inappropriate structures, leveraging and fees charged by managers, reveals a misalignment of interests between investors and fund managers. The fact that these structures fail to adjust to the needs of private investors represents a form of market failure requiring government intervention. Ottesen (2011) commented on this failure most succinctly when he said that 'the government must establish guiding principles and let the market mechanisms work within these established guidelines'.

4.4 Does current regulation encourage or hinder private investment?

Scholars and practitioners have observed that international regulations following on the heels of the financial crisis will prevent the private sector from closing the funding gap for investment in infrastructure (Hellowell and Vecchi, 2012). In order to respond to the challenges posed by international regulation and to mitigate their negative effects on private investments, governments will need to draw up various initiatives/schemes. The UK government has made concerted efforts in the area of infrastructure finance, and some examples of UK initiatives are specifically designed to encourage private sector investment. We point to the UK in particular, in our discussions of the immense value of infrastructure investments, because the UK rate of infrastructure investment has not kept pace with the needs of a modern economy and, as a consequence, the country has fallen behind many competitors. As Prime Minister Cameron advocated in 2012, if our infrastructure is second-rate, then our country will be too. In order to address this challenge, the formulation of a long-term plan for UK infrastructure was set out in the National Infrastructure Plan (NIP) 2011 and elaborated in the National Infrastructure Plan: Update December 2012. The Plan reinforces the UK Government commitment to complete more than 550 essential infrastructure projects; the report also claims that over £310 billion will be invested in infrastructure from 2012 onwards. The data estimated by the HM Treasury (2012*b*) for investment to 2015 and beyond clearly states the relevance of private sector participation towards the realisation of the UK NIP. According to Public Accounts Committee (2013), the Government expects 64% of its planned investment in economic infrastructure to be wholly owned and financed by the private sector. Like the European prospects, although the majority of the UK's future infrastructure projects are expected to be financed by the private sector, the level of private infrastructure investment is still insufficient (CBI, 2012).

With the introduction of Basel III in 2010 (international reform measures developed by the Basel Committee on Banking Supervision to strengthen the regulation, supervision and risk management of the banking sector), which is being implemented between 2013 and 2019, the Basel Committee sought to improve the resilience of the banking sector by enhancing the regulatory requirements for capital. According to the chief executive of Societe Generale, Frederic Oudea, Basel III will directly affect infrastructure projects (Cowell and Laurent, 2012). Under this new regulation, for the same amount of debt that banks gave prior to the economic downturn, banks will now have to allocate two to three times more capital. The implication here is that long-term investment will become very expensive in relation to banks' capital requirement (Reviglio, 2012). According to the Net Stable Funding Requirement (NSFR), banks must show stable funding in the long-term. In other words, banks need to have funding in place of at least one's year maturity to cover assets of one year maturity or more. Nevertheless, different assets will require different coverage. For instance, higher rated bonds will be treated more favourably (Linklaters, 2011).

Given the limits introduced to banks by Basel III, the burden of financial infrastructure now rests on institutional investors such as pension funds (Cowell and Laurent, 2012). However, the new insurance regulation (Solvency II), which replaced Solvency I in January 2014, will also be applicable to pension funds (FSA, 2012). Solvency II has been designed to reduce the risk of firm bankruptcy in the aim to protect policyholders and prevent market disruptions (FSA, 2012). Under this new regulation, pension funds will be obliged to meet higher capital requirement, which will make investing in infrastructure more expensive (Hellowell and Vecchi, 2012). At first, Infrastructure investments were treated as hedge funds, private equity and other types of equity. By not initially receiving different treatment from other assets, the government failed to clearly recognise infrastructure as a lower risk investment. However, as of September 2015, the EU Commission made amendments to the Solvency II framework in order to introduce the concept 'qualifying infrastructure investments' (European Commision, 2015). If an investment qualifies in the definition of infrastructure, then it benefits from a specific treatment. Nevertheless, despite improvements to the Solvency II regulation, further improvements are needed in order to guarantee that the regulation will not hinder private sector investment in infrastructure. Interestingly, empirical studies indicate that the risk/return profile of infrastructure assets is better than that of other investments; for instance, using data from the Preqin infrastructure database, Inderst (2010) demonstrated that, when compared to other funds between 1993 and 2007, infrastructure funds slightly outperform all funds except buyout and mezzanine funds. Like mezzanine funds, they show the most stable returns. Furthermore, infrastructure funds show the least dispersion of returns across all funds (volatility).

In July 2011, HM Treasury announced that UK guarantees of up to £40 billion would be available for infrastructure projects, particularly in transport, utilities, energy, and communications sectors (HM Treasury, 2012*a*). The scheme was launched to ensure that projects struggling to find private investment would proceed as planned. The guarantees apply to all projects that fulfil the criteria in the government's NIP 2011. Criteria include the ability to start construction within 12 months after the guarantee is given, that they are financially credible in limiting risks to the taxpayer, and they contribute positively to economic growth. As illustrated in the NIP (HM Treasury, 2012*b*), from the 75 enquiries received, projects with a capital value of £10 billion are pre-qualified for a UK guarantee. The purpose of the UK guarantees scheme is to make infrastructure projects more attractive to pension funds and to reduce the negative impacts of Solvency II.

Another UK government scheme dedicated to the pension fund industry is the new 'pension investment platform' (PIP), which is under the auspices of the UK pension funds and was created to support pension fund investment in infrastructure By following the examples set by other countries where the pension funds come together to invest under umbrella organisations, as in the Ontario Teachers' Pension Plan in Canada, HM Treasury hopes to achieve improved organisation and increased amounts of resources for UK infrastructure investment. In 2012, six pension fund schemes had raised £700 million of capital (Infrastructure Investor, 2012).

Until recently, the exposure of pension fund investments to partnership structures such as real estate, private equity and infrastructure funds, was limited to 15% of their assets. In an attempt to unlock pension investment in infrastructure, the government has raised the limits to 30%. It was estimated that raising the level to 30% will free up £22 million for infrastructure projects, specifically roads and rail (Graham and Menon, 2012). We have already discussed how concern about construction risk has led infrastructure investors to invest only in brownfields. According to Graham Robinson, an infrastructure specialist at Pinsent Masons, the new regulation to increase the limit of exposure to infrastructure of a pension fund portfolio from 15% to 30%, allows pension funds to invest more but it does not address the riskiness of the investment (Graham and Menon, 2012). Risk in infrastructure investments arises not only from construction risk but also from the amount of leverage of these investments. Many infrastructure funds have very high leverage, up to 80%-90%, so in order to address the increased leverage of infrastructure funds, the UK government could for example restrict the leverage level to 50% (Infrastructure Investor, 2012).

Lending will also be available for Public Private Partnership (PPP) projects struggling to obtain much needed private finance as long as they pass government approval procedures and get most of their debt and equity requirements from the private sector. The new PPP UK policy is now known as PF2. PF2 tackles the main drawbacks of the Private Finance Initiative (PFI) introduced in 1992 as a means of encouraging PPPs. One of the drawbacks of the PFI was that only specific risks were to be given to the private sector so the public sector would be burdened with the higher risk premium A study by Shaoul et al. (2008) on PFI projects in the UK health sector showed the high cost of private finance. In particular, they calculated an additional cost of £60 million a year as a result of private ownership. To counteract this problem in the new PF2, the government will act as equity stakeholder in the aim to reduce the increased cost. In the PFI it was also concluded that project completions were too slow. New measures were introduced in PF2 to ensure acceleration of delivery, such as frequent checks made by HM Treasury at the pre-procurement stage. Other changes include the introduction of hybrid structures, as discussed earlier; the 'split-finance' hybrid splits the funding between two investors: a bank and a pension fund, where the bank can fund a construction project such as a greenfield project and then exit after construction is complete. This arrangement would meet the Basel III requirement for shorter investments and would ensure higher liquidity. A pension fund can then invest in the project during its operation period and avoid construction risks.

PFI projects were based on financially complex systems in terms of collecting and presenting information on financial performance and assessment of risk (Fischbacher and Beaumont, 2003). But in PF2 there is greater transparency through various measures, for instance the requirement for the private sector to publish equity returns. Moreover, it introduces risk management strategies to minimise certain operation risks and intends to provide better allocation of risk (HM Treasury, 2012*b*).

Two other strategies have been introduced by the UK government in the aim to encourage transport investment. The Business Finance Partnership (BFP), operated by HM Treasury, was established in 2011 to increase capital for infrastructure through sources other than bank lending, and to assist mid-sized and small firms in being less reliant on banks. The government has set aside £1.2 billion under the BFP scheme for investments that must have private sector matching funds (HM Treasury, 2012*b*). In addition, the UK government has developed other non-bank sources of finance, including online platforms and leasing. The second strategy introduced by the UK government in October 2012 was the Green Investment Bank (GIB), which is funded with £3 billion and is expected to privately finance mainly waste and energy projects (HM Treasury, 2012*b*).

Although we have clearly demonstrated that the new international regulations will hinder private investment, it is also undeniable that governments can respond with their own instruments to encourage private investment in infrastructure, and in doing so, overcome the barriers thrown up by the banking industry's response to Basel III and Solvency II. However, despite the introduction of different UK policies and strategies, and the recognition of the value to be gained by investing in infrastructure, we suggest that even more has to be done to increase investor confidence in relation to the expected returns and to the risks associated with infrastructure investment. Infrastructure investments face significant regulatory risks. The development of a Sovereign Wealth Fund for investing in infrastructure could certainly provide significant resources for infrastructure investment in European governments.

4.5 Conclusion

Governments are aware of the multiplier effects which justify the high correlation between infrastructure investment and GDP growth. However, the drain of public resources due to the 2008 financial crisis means that the private sector must step in financially to support these investments. Investment banks and fund managers are convinced that, due to the physical, economic and financial characteristics of infrastructure, investing in infrastructure should be ideal for institutional investors like pension funds. Nevertheless, in this chapter we have discussed why private investors still have a tentative and cautious attitude towards infrastructure investment. Our examination of the availability and structure of the financial instruments currently in the market, as well as the regulatory environment in which they operate, has led us to the main obstacles still hindering private sector investment.

The extreme difficulty in calculating the performance of infrastructure funds is problematic for investors and consequently influences their choice of investments, which, in order to reduce risk, are often brownfield projects (Inderst, 2010). A broad and in depth research agenda to assess the investment characteristics and performance of infrastructure funds would increase confidence in this asset and encourage greater private sector investment, particularly in greenfield projects. Such research would also facilitate the design of new financial tools and flexible regulatory measures. For instance, we proposed in this chapter the increase of a 'split finance' model in order to stimulate greenfield investments. The advantages of the split finance model are that by addressing the needs of the investors according to the different phases of a project, not only does it release pension funds from the burden of construction risks, but it also complies with the Basel III regulation discouraging banks from long-term lending.

We also found that, at present, the structure of the infrastructure funds is often not fit for purpose. High leverage and high fees, together with short-duration, result in a clear misalignment of interests between investors and fund managers (Infrastructure Investor, 2012). Fund managers, investors and regulators need to find common ground through interaction and co-operation and commit to the restructuring of the current investment vehicles.

In our study of EU and UK infrastructure investment we observed that pension fund mechanisms are still too fragmented to pool sufficient financial resources for the required investments (Della Croce, 2012). Nevertheless, interesting initiatives such as PIP have been launched to address the shortfall of resources and to attract substantial capital for infrastructure investments. In this respect one cannot forget that infrastructure investments carry large political risk that needs to be reduced to its absolute minimum. For example, the establishment of a Sovereign Wealth Fund would anchor the advocacy of governments in infrastructure investment, thereby instilling greater confidence in its returns (Armistead, 2012).

It is undeniable that Infrastructure investment generates economic activity and consequently enhances growth. If European governments are truly keen to encourage and support economic growth, infrastructure investment is a reasonable choice. But importantly, governments need to be accompanied by the private sector, so they must first acknowledge the pitfalls and then set about resolving the private sector barriers in relation to infrastructure investment. The aim of the next chapter is to increase our understanding of infrastructure investments by examining different infrastructure sectors and sub-sectors in detail and analysing their role in the institutional portfolio. Having greater confidence in infrastructure investment will effectively increase the level of private sector participation and thus contribute fundamentally to the economic growth of countries.

Chapter 5

Portfolio of Infrastructure Investments: Analysis of European Infrastructure

5.1 Introduction

Since the early 2000s, first as a result of the availability of ‘cheap’ debt, then in response to the need for an alternative asset class after the financial crisis of 2008, private investors have become increasingly interested in infrastructure investments in Europe, Asia and the United States (Inderst, 2009). Infrastructure is often split into two categories: economic and social infrastructure (Giang and Pheng, 2014). Economic infrastructure consists of transport services (rail, ports, roads, and airports) and other services such as utilities, energy and telecommunications, whereas social infrastructure refers to public assets such as hospitals, schools and prisons (CSAM, 2010).

Infrastructure as an asset class has attracted particular attention, not only because of the distinctive investment characteristics of the sector but also in response to the recent global financial crisis, both of which have compelled governments around the world to turn to infrastructure investments for their economic recovery (RREEF, 2011). However, European governments remain cautious investors. Despite the willingness of many governments to invest in infrastructure as a means of boosting their economies, budgetary constraints imposed on European governments due to the financial recession have dampened investor enthusiasm towards this investment class (Gomez and Vassallo, 2014).

Infrastructure investment is nevertheless also increasingly on the agendas of private investors who are examining these investments with great interest. Recent analyses by Preqin (2013a,b, 2014) indicate that institutional investors like pension funds continue to allocate significant amounts of capital into infrastructure assets across the globe, giving exposure to European infrastructure assets in particular. The Preqin analyses demonstrate that, starting from 2010, European fundraising levels have doubled year-on-year and that 42% of infrastructure funds are allocated in European infrastructure. Moreover, they state that the annual European infrastructure deal flow has risen significantly as political, regulatory and economic conditions have become more secure, and in response to the numerous investible assets with uncorrelated and stable returns.

Despite the reported higher demand for European assets, specific research in this area is still limited, mainly due to scant empirical data. However, before any investment decisions are made, it is advisable, according to Khatri et al. (2011), for investors to be informed about the performance of individual infrastructure systems. Most of the available studies concentrate on global infrastructure (RREEF, 2011) and the Australian infrastructure market, which is the most mature market (Finkenzeller et al., 2010, Newell et al., 2011, Peng and Newell, 2007). To date, the research dedicated to the European infrastructure class (RREEF, 2010) often examines listed infrastructure as a whole, and gives little attention to the economic characteristics of this investment class. Moreover, most of the aforementioned research assumes that all of the infrastructure sectors have the same distinctive and attractive investment characteristics. However, there is neither any research that corroborates the homogeneous characteristics of infrastructure, nor are there studies that give close scrutiny to, and provide thoroughgoing discussions about, specific infrastructure sectors. The present thesis suggests that infrastructure is a new vast asset class consisting of many different sectors, each with its own features and historical performance. In fact, Hall et al. (2014) agree strongly that one of the remaining major challenges is to study the complexities of the sector in order to better understand the long-term performance potential of infrastructure. The aim in this chapter is to examine whether the proposed investment characteristics of infrastructure are indeed present in all the different infrastructure sectors and sub-sectors, and to discuss the implications of our findings for the construction of infrastructure portfolios. Against this background, the objectives of this analysis are twofold. The first research objective is to understand the investment profile of each infrastructure sector and sub-sector. The second and most important objective is to analyse the significance of this sectorial and sub-sectorial differentiation in the investment profile.

To address the first objective, we compare the investment characteristics of a number of different European infrastructure sectors and sub-sectors with those of more traditional assets, thus allowing us to carry out a robust analytical examination of the investment profile of different infrastructure sectors and sub-sectors. We then examine whether it is beneficial for an investor to build a portfolio of different infrastructure sectors or if it is still possible to obtain diversification benefits by investing in one sector only. This chapter emphasises the importance of proving the optimality of portfolios, even when investments are focused in a single sector, as in that way the manager of the portfolio will still be able to diversify and also develop a deeper understanding of the behaviour of the sector. Managers will learn how to assess the performance of the investments, which is essential if more private participation in infrastructure investments is to take place. It is widely argued that the performance measurement is a key determinant to the success of a project (Liu et al., 2014).

5.2 Data and research methodology

In order to address the two objectives of this chapter, as discussed in chapter 3, we apply the data collected from Thomson Reuters Database. These date include historical time series of monthly returns of European indices over a time span of 11 years (2003-2013) for the infrastructure sector analysis, and weekly returns of European indices over a 10-year time span for the sub-sector analysis (2004-2013). Risk-free monthly returns from the same period are collected from the Kenneth R. French Data Library. The risk-free assets used are Treasury monthly T-bills. The sectors and sub-sectors used, along with the descriptive statistics of the data, can be found in chapter 3.

The analysis of the European infrastructure asset performance is developed over a three-step process. First we calculate the annualised return, annualised volatility and Sharpe Index of each index for the whole period (for the sector analysis from Q1.2003 to Q4.2013 and for the sub-sector analysis from Q1.2004 to Q4.2014). The Sharpe Index shown in Equation 5.1 is a standard industry measure for calculating risk-adjusted returns. This measure quantifies an asset's average return earned in excess of a risk-free, guaranteed investment such as Treasury bills, per unit of volatility. The higher the Sharpe ratio, the more attractive its return relative to its risk. The Sharpe ratio is used to rank the assets, because a higher Sharp ratio means that the asset's risk/return relationship is more optimal. In this step one, the three results of the calculations are next used to compare the performance among the different assets over the long-term.

The Sharpe Index is calculated by the following formula:

$$SharpeIndex = \frac{Return_i - Return_{R_f}}{SD_i} \tag{5.1}$$

where: $Return_i$ is the return of asset i and $Return_{R_f}$ is the return of the risk-free asset (in this research Treasury monthly T-bills are used) and SD_i is the Standard Deviation of asset i.

The second step of the process is to evaluate the diversification benefits among infrastructure assets and with other traditional assets (e.g., Stocks, Real Estate and Government Bonds) based on the asset returns matrix correlation and rolling correlations across our study period. The time span we examine is intriguing because it covers the period of the most recent financial crisis. Therefore, as a third performance test we contract the dataset from Q4.2007 to Q2.2009 so that we may focus on the financial crisis period. The annualised return, annualised volatility and Sharpe Index are re-calculated for these three years in order to examine the robustness of listed infrastructure sectors and sub-sectors. The Sharpe Index is used once again to rank the assets because its meaning remains the same before and during the crisis, as long as the returns and volatility of the risky asset and the returns of the risk-free asset for the same period are used. Assets with a higher Sharpe Index demonstrate that the better returns have been relative to the risk undertaken.

For the second objective of this chapter: to prove which is the best way to construct a portfolio that invests in infrastructure, the author performs a portfolio historical analysis using the standard Markowitz (1952, 1959) mean-variance portfolio optimisation technique as described in chapter 3. The return of the portfolio is calculated as:

$$Return_{portfolio} = \sum_{i=1}^{n} x_i * ri \tag{5.2}$$

where, x_i represents the ith/inidividual security or asset in the portfolio and r_i the return of the individual security.

Markowitz (1959) defined the variance of the portfolio as:

$$Variance_{portfolio} = \sum_{i=1}^{n} x_i^2 * SD_i^2 + 2\sum_{j=1}^{n}\sum_{i>1}^{n} x_i x_j r_{ij} SD_i SD_j \tag{5.3}$$

where $i \neq j$, $SD_p = \sqrt{Variance_{portfolio}}$, r_{ij} is the correlation coefficient between the ith and jth variables and SD_i is the Standard deviation of the ith variable.

The efficient frontiers of each portfolio are drawn in order to illustrate the risk/ return characteristics of all the optimal portfolio combinations. This is important for investors, as by looking at the efficient frontier of the optimisation, they can determine which optimal portfolio they want to invest in depending on their risk appetite. For instance, a risk averse investor can choose to invest in the weight combination of the assets that give the minimum variance portfolio. On the other hand, a more risky investors would choose to invest in the weight combination of assets that gives more returns for the same amount of risk.

As a lesson learned after the most recent financial crisis, tail-risk analysis has proved to be a vital test for evaluating investors' portfolio risk. Therefore, the Mean-Conditional Value at Risk (M-CVaR) optimisation is also estimated in this thesis. The results of the M-CVaR optimisation are thereafter compared with the Mean-Variance framework in order to check their robustness. As seen in chapter 3 one of the arguments against the approach of Markowitz (1952, 1959) is that the MVO measures the risk of the portfolio as the standard deviation but this is only valid when the returns are normally distributed. For this reason, a second portfolio optimisation technique is then carried out, the M-CVaR portfolio, which uses simulations that do not necessarily assume that the distribution of the data is normal. The M-CVaR calculates the highest returns obtainable for a given level of CVaR at the 95% probability level.

The VaR (x) for portfolio x means that with a $(1-\alpha)$ probability, the returns will not fall below this level. The Conditional Value-at-Risk, also known as 'expected shortfall', is the expected loss of the portfolio returns above the $VaR_\alpha(x)$. Following (Rockafellar and Uryasev, 2002) and as described in chapter 3:

The α-Conditional Value-at-Risk for a portfolio of $x \in \mathbb{X}$, is defined as:

$$CVaR_a(X) = \frac{1}{1-\alpha} \int_{f(x,y) \geq Var_\alpha(x)} f(x,y)p(y)dy. \tag{5.4}$$

where, α is the probability level such that $0 < \alpha < 1$. In this study the probability level is 0.95. $f(x,y)$ is the loss function for a portfolio of x and asset return y. $p(y)$

is the probability density function for asset return y. VaR_α is the value-at-risk of portfolio x at probability level α.

The $VaR_a(X)$ is defined as:

$$VaR_a(X) = \min\{\gamma : P(X \geq \gamma) \leq 1 - \alpha\} \tag{5.5}$$

The results of the two optimisations are compared in two ways:

- The risk proxies are converted in order to compare the two portfolios. Using the CVaR portfolio weights, we can calculate the Mean-Variance Risk of the 10 M-CVaR efficient frontier portfolios. This will enable us to compare the efficient frontiers of both optimisations and observe any differences.
- By using area plots, the author is able to visualise the weights of both the mean-variance and the M-CVaR and thereafter compare the weights of the chosen assets.

Before we examine the most beneficial way to construct a portfolio with infrastructure investments, our first objective in Section 5.3.1 is to evaluate the significance of European infrastructure in traditional portfolios and to verify whether an investor can still obtain diversification benefits by focusing only on a single sector. We consider two main sectors: Transport, which the author identifies as stable, and Energy, which due to the present innovative but disruptive energy technology, is described as relatively unstable. Energy has a less attractive financial performance due to its ambiguous status.

The following portfolios are optimised using the programming language Matlab:

- Portfolio 1 includes only European traditional assets (Stocks, Real Estate and Government Bonds).
- Portfolio 2 includes the same assets as Portfolio 1, plus all of the infrastructure sectors.

- Portfolio 3 specialises only in the energy sub-sector assets (Natural Gas, Electricity, Fossil Fuels, and Renewable Energy) within a traditional portfolio.
- Portfolio 4 specialises only in the transport sub-sector assets (Airports, Ports and Toll Roads) within a traditional portfolio.

5.3 Results

5.3.1 Objective 1: Performance analysis of different infrastructure sectors and sub-sectors

The first objective, the performance analysis of different infrastructure sectors and sub-sectors, is divided in two parts: the sectorial analysis where we examine the performance of four different infrastructure sectors (Energy, Telecommunications, Utilities, and Transport) among traditional assets (Stocks, Real Estate and Government Bonds). The second analysis repeats the same performance tests but concentrates on the specific sub-sector components of two infrastructure sectors (Energy and Transport). In the second analysis we examine the performance of Natural Gas, Electricity, Fossil Fuels, and Renewable Energy when focusing only on the Energy sector, and the performance of Airports, Ports and Toll Roads when focusing only on the Transport sector. In the sub-sector studies we compare infrastructure assets with the same traditional assets: Stocks, Real Estate and Government Bonds (as in the sector analysis). For both analyses we first present the results of the whole dataset in order to compare the long-term historic behaviour of the assets. Thereafter, we inspect the contracted dataset to verify the robustness of the assets during financial crisis. Our final step in this chapter is to examine the diversification benefits among the different assets by calculating the inter-correlation matrix for each analysis.

Table 5.1: Historical Performance Analysis of European Infrastructure Sectors for Period Q1.2003-Q4.2013

European listed asset	Annualised Return	Annualised Volatility	Sharpe Index	Rank
Energy	4.76%	21.86%	0.153	6
Telecoms	5.24%	19.21%	0.199	5
Utilities	5.96%	20.74%	0.220	3
Transport	9.35%	23.81%	0.334	2
Stocks	2.55%	18.19%	0.063	7
Real Estate	6.56%	24.47%	0.210	4
Government Bonds	5.46%	10.33%	0.392	1

European Infrastructure sector performance analysis

Table 5.1 shows the performance of European assets for the period 2003-2013. The four listed infrastructure sectors indicate significant variation in their performance, proof positive that infrastructure should not be treated as a singular asset, and that close attention should be paid to the behaviour and historical performance of infrastructure's individual sectors.

As can be seen in Table 5.1, Transport shows a strong performance over the whole sample period, with a return of 9.35% and volatility at 23.81%. It is the best performing infrastructure asset, with the highest Sharpe Index of 0.334. This is not a surprising finding, as European transport is a very stable sector. However, Energy shows the worst performance of all the infrastructure assets, with an annual return of 4.76%, annual volatility of 21.86%, and a Sharpe Index of 0.153. One reason for the under-performance of some infrastructure sectors compared with Transport is due to the fact that Transport assets are critical and are therefore less impacted by changes in risk preferences. For example, the risk aversion that followed the financial crisis drove people away from technological investments such as Telecom and Renewable Energy investments. When we compare the performance of the infrastructure assets with traditional assets we can conclude on the basis of their higher Sharpe Indices that all of the listed infrastructure sectors (Transport, Utilities, Energy, and Telecoms) perform better than Stocks, and are less volatile than Real Estate. But Government Bonds shows the highest Sharpe Index at 0.392.

Table 5.2: European Infrastructure Sector Performance Analysis during the Financial Crisis Q4.2007-Q2.2009

European listed asset	Annualised Return	Annualised Volatility	Sharpe Index	Rank
Energy	-25.4%	30.4%	- 0.856	3
Telecoms	-30.0%	24.6%	-1.24	5
Utilities	-30.3%	31.2%	-0.992	4
Transport	-28.2%	35.1%	-0.822	2
Stocks	-41.3%	30.6%	-1.37	6
Real Estate	-53.9%	37.8%	-1.44	7
Government Bonds	4.22%	14.4%	0.247	1

European Infrastructure sector performance during the financial crisis

As mentioned above, the time period of the data is particularly interesting because it captures the effects of the financial crisis of 2008. In order for us to isolate the effect of the crisis period, and to compare the robustness of listed infrastructure sectors during recessions, the dataset is contracted to (Q4. 2007-Q2. 2009).

The results of the annualised return, annualised volatility, and Sharpe Index for the period of the crisis are presented in Table 5.2. From the results one can conclude that all assets, except Government Bonds, were severely affected by the crisis. However, we can also observe that all listed infrastructure sectors were less negatively affected than Stocks and Real Estate, as all infrastructure assets have a higher Sharpe Index than Stocks and Real Estate.

Diversification Benefits among assets

According to Hall et al. (2014), there is little experience in thinking cross-sectorally about infrastructure system performance, and this prevents us from understanding the long-term performance of infrastructure. Nevertheless, by calculating the correlation among the monthly returns of all assets, the author is able to evaluate if there are any diversification benefits among the different listed infrastructure sectors, and between the different infrastructure and traditional assets.

Table 5.3: Cross Asset Correlation Matrix for Monthly Returns Q1.2003-Q4.2013

Assets	Energy	Telecoms	Utilities	Transport	Stocks	Real Estate	Government Bonds
Energy	1						
Telecoms	0.693	1					
Utilities	0.776	0.824	1				
Transport	0.720	0.772	0.845	1			
Stocks	0.727	0.558	0.664	0.610	1		
Real Estate	0.637	0.683	0.792	0.760	0.641	1	
Government Bonds	0.601	0.709	0.707	0.665	0.206	0.644	1

The results of the cross asset correlation matrix presented in Table 5.3 indicate that infrastructure sectors are indeed highly correlated. An explanation is given by (Hall et al., 2014, p.11), who assert that demand for infrastructure is highly correlated due to the final demand associated with population and economic growth, and because of intermediated demands among infrastructure sectors. For example, as (Hall et al., 2014) points out, a change in demand for electric vehicles would imply a change in demand for the energy sector. This high correlation among the different listed infrastructure sectors proves that there is no benefit gained from constructing a portfolio that invests only in different listed infrastructure sectors.

All of the listed infrastructure sectors in Table 5.3 also show high correlation with traditional assets. The high correlation with Stocks is consistent with the literature, which is not surprising, because the present study uses indices based on publicly-traded infrastructure companies (Inderst, 2009). Low correlation with traditional assets therefore cannot be confirmed in this study.

Rolling Correlations

Rolling correlations were plotted to examine the correlation of each infrastructure sector with traditional assets over the years. In Figure 5.1, it's shown that after the financial crisis of 2008, the correlation of EU infrastructure sectors with government bonds has increased substantially. Generally, since the crisis the correlation of all the infrastructure sectors with government bonds is moving at the same level. However, before the crisis there is substantial evidence that showed that each sector had a different diversification benefit with government bonds. For instance, for a period during 2006, while the correlation of all infrastructure sectors was decreasing creating a potential to diversify, the energy sector correlation with government bonds was increasing. Furthermore, during 2004-2005, Transport was offering a lot of diversification benefits with government bonds, while other infrastructure sectors such as Energy or Utilities were showing increasing correlation.

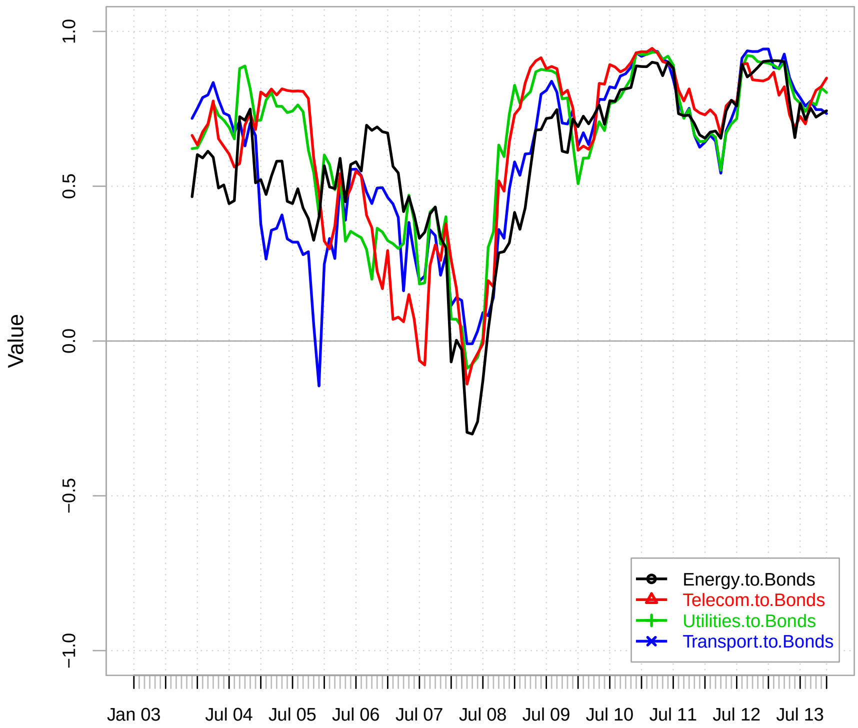


FIGURE 5.1: Rolling Correlations of EU infra sectors with Government Bonds

In Figure 5.2 and Figure 5.3, a similar effect can be observed. The correlations with traditional assets before the crisis show substantial differences among infrastructure sectors, but after the crisis infrastructure sectors' rolling correlations with traditional assets seem to move together. This confirms that, during a crisis, the correlation among assets increases, thus eliminating the diversification benefits. Nevertheless, we would argue that close attention must be paid to the sector level: even though the rolling correlations among assets move together, the extent of

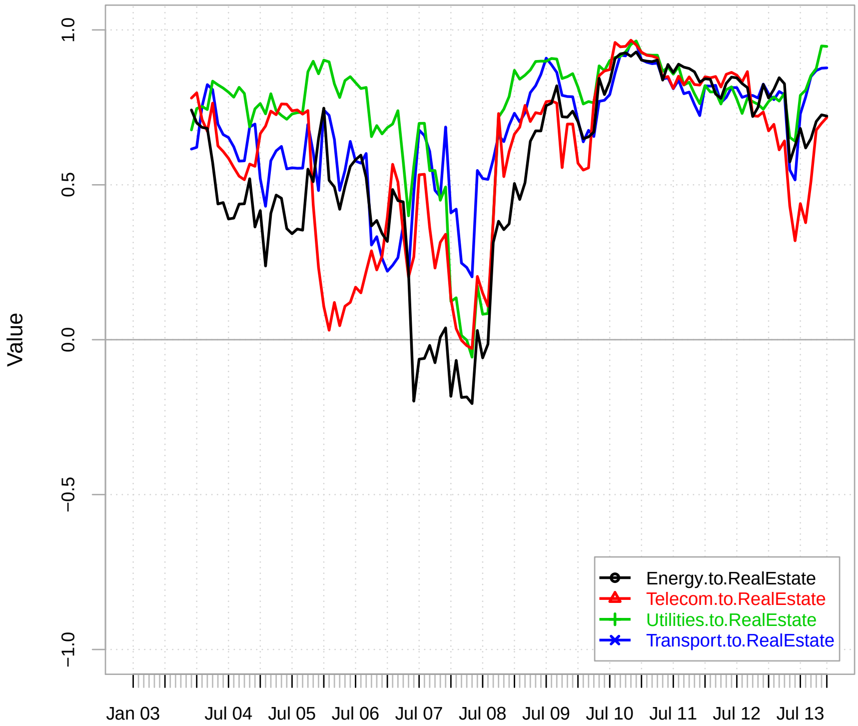


FIGURE 5.2: Rolling Correlations of EU infra sectors with Real Estate

the movement of the correlation is different. For instance, in Figure 5.3 we see that even though in July 2013 the rolling correlation of infrastructure sectors with Stocks decreased, (offering in this way a diversification benefit), the extent of the benefit to each infrastructure sector differs substantially. For instance, Transport showed a very low to negative correlation with Stocks while Energy showed a medium to high correlation level.

Another check done on the differences among infrastructure sectors was to draw the rolling correlation of each infrastructure sector in order to examine the extent to which the sectors move together. The results are given in Figure 5.4 and Figure 5.5. In recent years, specifically in the years following the financial crisis, we can safely say that infrastructure sectors move fairly closely together, as indicated by the medium to high correlation the sectors exhibit with each other across the period. However, prior to the crisis of 2008 the infrastructure sectors do not show

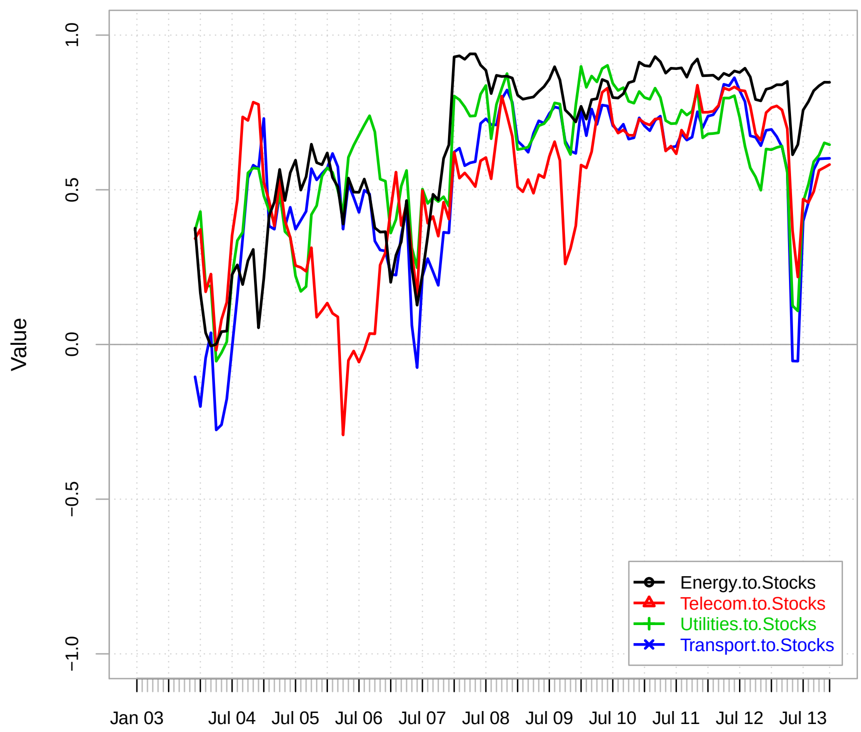


FIGURE 5.3: Rolling Correlations of EU infra sectors with Stocks

high correlation; in fact, some sectors (Transport and Energy) indicate negative correlation with each other. This finding shows that, despite recent data, listed infrastructure sectors do not move together, strongly suggesting that each sector must be distinguished from the others. It is noteworthy that this finding also has important implications for regulation, which in general treats infrastructure as a single sector.

Robustness Analysis

To avoid bias, a second index was selected for all traditional assets (Stocks, Real Estate and Government Bonds) as a control in order to check if the obtained results are index-specific. Nearly all of the conclusions are again confirmed in the robustness analysis. One difference is that in the robustness analysis the author observes low correlation between infrastructure sectors and Government Bonds.

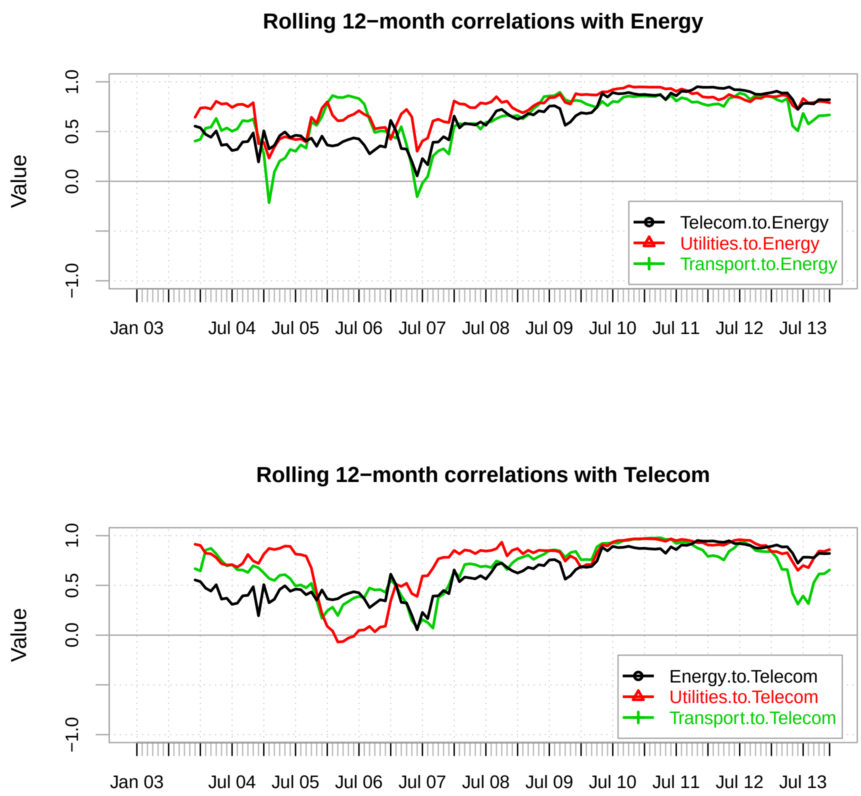
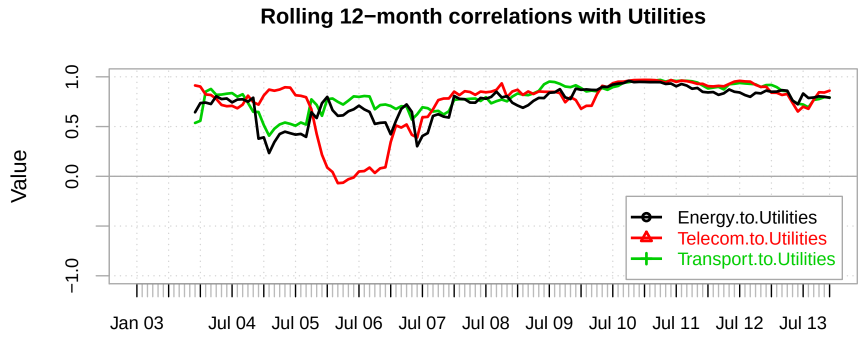


Figure 5.4: Rolling Correlations of EU infra sectors with Energy and Telecom

This finding indicates that there are diversification benefits with infrastructure sectors and Government Bonds in a portfolio.

5.3.2 European Infrastructure sub-sector analysis

In this section we analyse the differences between sub-sector assets (Energy and Transport). These two sectors are particularly interesting because they behave very differently. The Energy sector is highly changeable, not only in terms of performance, but also due to an unstable regulatory framework (i.e. EU environmental regulation, national renewable energy incentives, feed-in tariffs) resulting in higher political risk. Conversely, the Transport sector represents a relatively sturdy sector with a fairly stable regulatory framework.



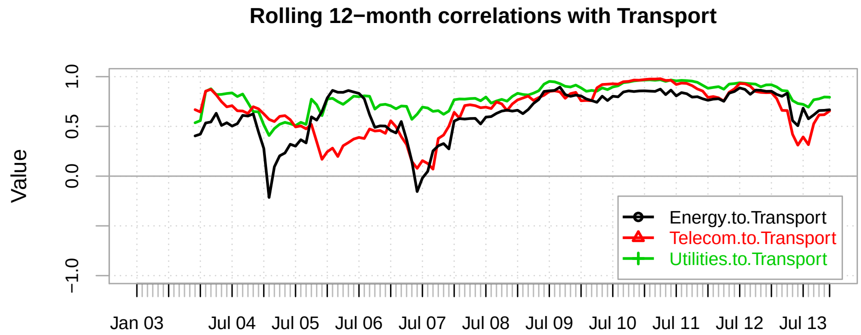


FIGURE 5.5: Rolling Correlations of EU infra sectors with Utilities and Transport

The results of the long-term performance of the Energy sector are presented in Table 5.4. In the European Energy sub-sector performance analysis, one can notice that Electricity was the best performing energy asset over the period examined, with a Sharpe Index of 0.258. However, Fossil Fuels and Renewable Energy perform the worst of all sub-sectors, with Sharpe Indexes of 0.036 and 0.007, respectively. There are certainly reasons that justify the poor performance of the Renewable Energy sub-sector. The inconsistency of the regulatory and fiscal regimes related to Renewable Energy in, e.g., Spain and Germany, has produced uncertainty about investing in renewable energy. Moreover, renewable energy faced stiff competition with other energy sub-sectors, e.g., natural gas and oil, which decreased in price after the financial crisis. However, there is a very positive outlook for renewable investments due to governments having to meet their European targets for CO_2 emissions.

Table 5.4: European Infrastructure Energy and Transport Subsector Historical Performance Analysis for Q1. 2004-Q4. 2013

European listed asset	Annualised Return	Annualised Volatility	Sharpe Index	Rank
Natural Gas	5.27%	18.03%	0.200	5
Electricity	6.74%	19.72%	0.258	3
Fossil Fuels	2.62%	26.76%	0.036	9
Renewable Energy	1.89%	33.82%	0.007	10
Airports	7.90%	20.26%	0.308	2
Ports	11.06%	24.33%	0.386	1
Toll Roads	4.20%	21.73%	0.117	6
Stocks	3.65%	19.69%	0.101	7
Real Estate	3.90%	27.90%	0.080	8
Government Bonds	4.01%	10.89%	0.215	4

When we compare the Energy sub-sectors with traditional assets, we can observe that all Energy sub-sectors, apart from Renewable Energy, show lower volatility than Real Estate, but Government Bonds has the lowest volatility of all of the assets.

We also provide Transport sub-sector analysis results in Table 5.4. In the table, Ports has the highest Sharpe Index of 0.386 and is therefore the best performing asset. Airports also show a good Sharpe Index of 0.308. On the other hand, the performance of Toll Roads is much worse than Airports and Ports, with a Sharpe Index of 0.117. This is as expected, because Ports and Airports not only obtain revenue from their transport services but also from other services in and around airports and ports (i.e., restaurants, shops etc.). In contrast, most Toll Roads accrue all their revenue solely from transport demand. Obtaining revenue from non-infrastructure sources is something that is increasingly seen in the financing of infrastructure. A strong example of this are railways, in which a significant amount of their revenues are coming from non-farebox sources such as advertising, the station retail, land value uplifts and transit oriented developments built on top and around the station. Non-infrastructure value capture is of growing important as they offer diversification of risks. For instance, in a transportation asset, obtaining revenue from retail and land value mechanisms makes the business model of the asset no longer dependent solely on traffic demand.

Furthermore, Ports and Airports are dynamic and productive sectors. For instance, even with the crisis, the gross weight of seaborne goods handled in all European ports has increased in recent years (Eurostat, 2015). Whereas many Toll Road projects face insufficient financing due to investor unwillingness to fund projects exposed to traffic demand risk. As Carpintero et al. (2013) showed, although some contracts aim to mitigate traffic risks either through flexible contracts or government guarantees, other types such as fixed term contracts assign traffic risk completely to the private sector and give no guarantees. Despite this observation, however, Gomez and Vassallo (2014) find that in all European countries revenues generated from road charges exceed road expenditures with enough money remaining to also subsidise other policies.

Compared to traditional assets, all of Transport's sub-sectors show lower volatility than Real Estate. Once again, in the Transport analysis Government Bonds shows the lowest volatility of all the sectors.

European Infrastructure sub-sector performance during the financial crisis

Let us now repeat the analysis of the previous section but with a narrower dataset to capture only the period of the financial crisis. Analysis results are given in Table 5.5. We find that the performance of the infrastructure sub-sectors during the years of the financial crisis is consistent with the infrastructure sector results. All infrastructure sub-sectors are less negatively affected by the financial crisis than Real Estate and Stocks. One can here point to the robustness of infrastructure investments during a downturn in macroeconomic conditions. However, none of the infrastructure sub-sectors exceeds Government Bonds in terms of robustness; Bonds consistently show the best performance of all assets during the crisis, with a positive Sharpe Index of 0.22.

Table 5.5: European Infrastructure Subsector Performance Analysis during the Financial Crisis Q4. 2007-Q2. 2009

European Listed Asset	Sharp Index
Natural Gas	-0.82
Electricity	-0.96
Fossil Fuels	-0.60
Renewable Energy	-0.85
Airports	-0.70
Ports	-1.10
Toll Roads	-1.05
Stocks	-1.09
Real Estate	-1.17
Government Bonds	0.22

Table 5.6: Cross Asset Correlation Matrix for Energy Subsector Monthly Returns Q1. 2004-Q4. 2013

Assets	Fossil Fuels	Renewable Energy	Natural Gas	Electricity	Stocks	Real Estate	Government Bonds
Fossil Fuels	1						
Renewable Energy	0.688	1					
Natural Gas	0.559	0.475	1				
Electricity	0.726	0.722	0.523	1			
Stocks	0.797	0.729	0.488	0.825	1		
Real Estate	0.734	0.652	0.485	0.658	0.779	1	
Government Bonds	0.427	0.260	0.335	0.199	0.155	0.461	1

Diversification Benefits among Sub-sector assets

We cannot overemphasise the importance of interdependence among the different infrastructure assets in the quest to understand the behaviour of infrastructure systems. In this section we assess the diversification benefits of the Transport and Energy sectors in order to evaluate whether correlation benefits exist in single infrastructure sectors, and if they do, we calculate the benefit in each sector.

The results for the Energy and Transport sector are presented in Tables 5.6 and Table 5.7, respectively. Generally, we can observe high correlation in both sectors among all Energy and Transport infrastructure sub-sectors with Stocks and Real Estate. However, for some assets low correlation with Government Bonds is observed. These results are also consistent with the sector robustness analysis.

Table 5.7: Cross Asset Correlation Matrix for Transport Subsector Monthly Returns Q1. 2004-Q4. 2013

Assets	Ports	Airports	Toll Roads	Stocks	Real Estate	Government Bonds
Ports	1					
Airports	0.362	1				
Toll roads	0.390	0.648	1			
Stocks	0.425	0.686	0.873	1		
Real Estate	0.456	0.685	0.710	0.779	1	
Government Bonds	0.294	0.460	0.245	0.209	0.516	1

In relation to the correlation among the sub-sectors, however, we can observe that there is indeed some low correlation within the Transport and Energy sub-sectors; this finding is significant because it indicates that an investor can obtain diversification benefits even when investing only in the Transport or Energy sector.

After having analysed our first objective for this chapter, we can confirm that infrastructure is comprised of many different heterogeneous assets, each with its own specific performance. In response, we suggest that fund managers should develop expertise in specific sector and sub-sector elements of an infrastructure investment package in order to accurately and thoroughly comprehend the performance and behaviour of their investments.

5.4 Results Objective 2: How to construct a portfolio of infrastructure investment?

In this section we tackle the second objective of this chapter: how to build an infrastructure investment portfolio; four different portfolios are analysed:

- Portfolio 1 includes only European traditional assets (Stocks, Real Estate and Government Bonds).
- Portfolio 2 includes the same assets as Portfolio 1 plus the addition of all infrastructure sectors.

- Portfolio 3 specialises only in the Energy sub-sector assets (Natural Gas, Electricity, Fossil Fuels, and Renewable Energy) within a traditional portfolio.
- Portfolio 4 specialises only in the Transport sub-sector assets (Airports, Ports and Toll Roads) within a traditional portfolio.

The results of the four different portfolio scenarios are presented in the Mean-Variance framework and then compared with the M-CVaR optimisation. In regard to building a portfolio of infrastructure, what we find most interesting for each scenario in the Mean-Variance framework is whether a higher Sharpe Index is achieved by combining different assets instead of investing only in the best performing asset of each scenario.

5.4.1 European Portfolio analyses with and without infrastructure

Portfolio 1 : European traditional assets

Investing only in Government Bonds gives a Sharpe Index of 0.392, while investing only in Real Estate or only in Stocks yields a Sharpe Index of 0.210 and 0.063, respectively. By creating a portfolio that combines Stocks, Real Estate and Government Bonds, one cannot achieve a Sharpe Index higher than if one were to invest only in Government Bonds; this result proves that in terms of the Sharpe Index ratio, it is always more beneficial to invest only in Government Bonds than to combine a portfolio of different traditional assets. However, depending on the risk attitude of an investor, one can combine the three traditional assets to achieve either a lower risk by accepting a lower return or, if more risk-loving, to accept a higher risk for a higher return (The Efficient Portfolio Frontier for this optimisation can be found in Appendix A).

Portfolio 2 : same assets as Portfolio 1, plus the addition of all listed infrastructure sectors

Investing in a multi-asset portfolio of traditional European assets and listed infrastructure sectors is clearly beneficial. As we can notice in Figure 7.6, including infrastructure in a traditional European portfolio during the period 2003-2013 depicts an outward shift in the efficient frontier. The implication here is that for the same amount of risk investors can obtain higher returns.

The portfolio that maximises the Sharpe Index invests in Transport infrastructure (21.4%) and Government Bonds (78.6%) only and achieves a volatility of 12.1%, a return of 6.29%, and a Sharpe Index of 0.402. By including infrastructure in a traditional portfolio, we can obtain a higher Sharpe Index than by investing in any asset on its own. It is noteworthy from Appendix A, that in none of the efficient frontiers is it optimal to create a portfolio investing in many infrastructure sectors. This finding verifies our earlier observation: there are no diversification benefits between different listed infrastructure sectors.

As a sensitivity analysis, a second optimisation technique is undertaken, the M-CVaR optimisation, to check the results (See Appendix A). To compare the two optimisations, the monthly Mean-Variance risk using the weights of the M-CVaR optimisation is calculated to convert from one risk to another. This enables the conversion of the efficient frontiers of the M-CVaR optimisation to a mean-variance plot. Thus, as illustrated in Figure 5.7, the researcher draws the Mean-Variance Portfolio Efficient Frontiers for both techniques and compares the differences. From Figure 5.7 we can notice that the Mean-Variance portfolio results are quite robust, as the two frontiers are highly similar with small differences at the lower level of the frontiers.

The second performance test compares the weights of the assets in the efficient portfolios of the two optimisations. Figure 5.8 visualises the weights of both optimisations using area plots. The only difference observed in the allocation of the assets between the two optimisations is that the MVO gives more weight to

Stocks than the M-CVaR optimisation does. However, we observe that both optimisations choose to invest in the same assets: Government Bonds, Transportation and Stocks. We can therefore verify that infrastructure is a good addition to a traditional portfolio, and that sectors do not mix in the construction of optimal portfolios.

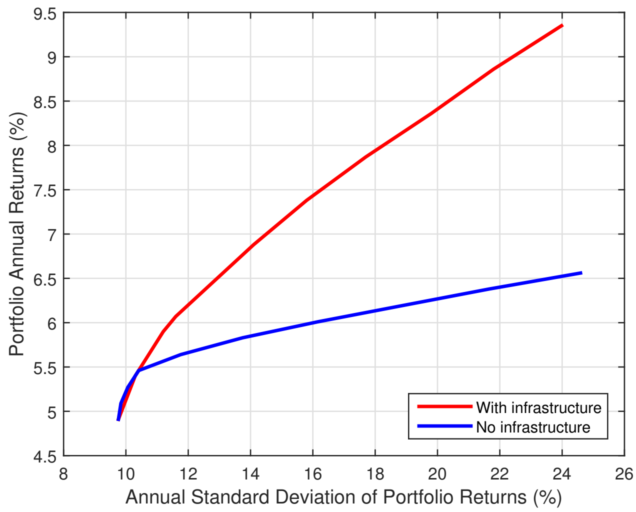


FIGURE 5.6: Efficient Frontiers for Portfolios 1 and 2

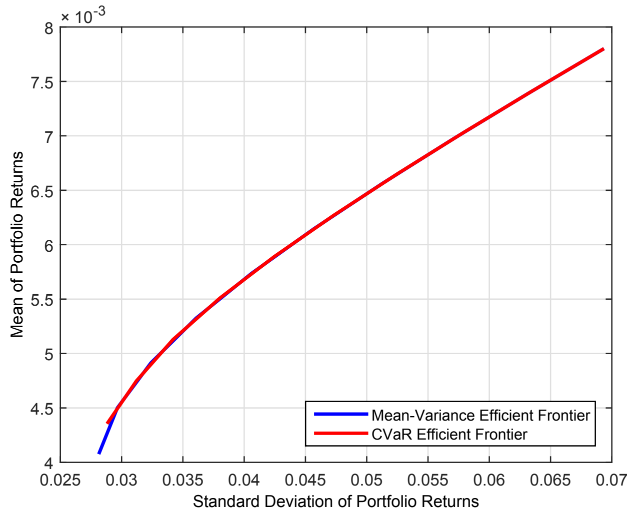


FIGURE 5.7: Efficient frontiers for the mean-variance and M-CVaR optimisation of Portfolio 2

5.4.2 Sub-sector Portfolio Analysis

The results of the previous portfolio analysis show that, in European infrastructure, a portfolio that invests in different infrastructure sectors is not optimal. For

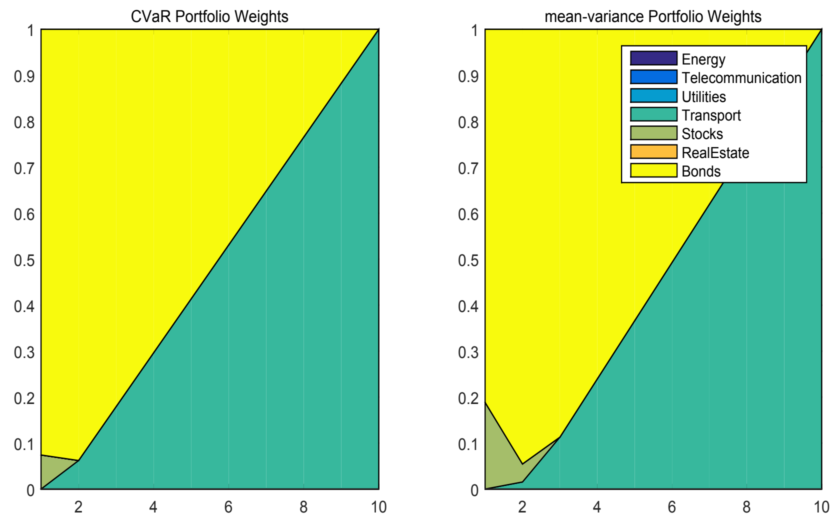


FIGURE 5.8: Weights comparison for portfolios mean-variance and M-CVaR optimisation of Portfolio 2

this reason, in the third and fourth portfolios the diversification benefits arising from investing in a single infrastructure sector alone is calculated. As mentioned above, we focus in this chapter on the Energy and Transport sectors because we want to detect the differences arising when investing only in a stable sector, e.g., Transport (where political risks are fewer) compared to the relatively new and unstable Energy sector.

Portfolio 3 : Energy sub-sector assets -Natural Gas, Electricity, Fossil Fuels, Renewable Energy

Portfolio 3 includes only Energy sub-sector assets within a traditional portfolio. As seen in the correlation analysis, modest diversification benefits are found in the Energy sector. The portfolio that maximises the Sharpe Index invests 55.7% in Government Bonds, 37.2% in Electricity and 7.09% in Natural Gas. The highest Sharpe Index achieved is 0.312, higher than the Sharpe Index obtained by investing in any single asset. The optimal portfolio annual return is 5.15% and the annual volatility is 11.2%. Some sectors, e.g., Renewable Energy and Fossil Fuels, are not included in the optimal portfolio; this observation may be due to certain sectors being over-valued by the market. However, there are other possible explanations for the exclusion of Renewable Energy and Fossil Fuels, such as government intervention or the ethics and values of the individual fund.

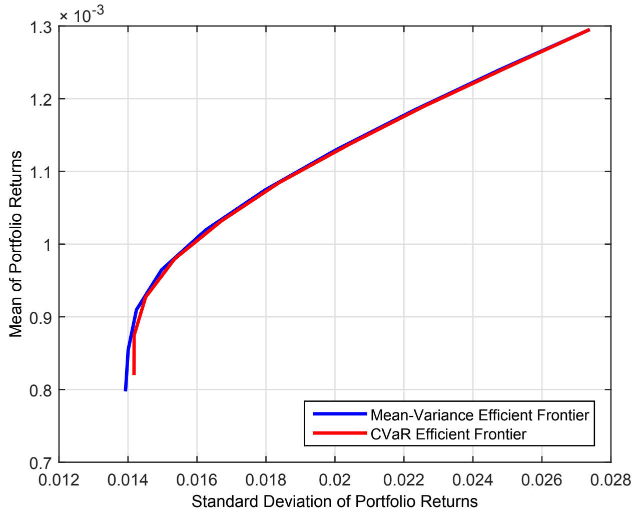


FIGURE 5.9: Efficient frontiers for portfolios mean-variance and M-CVaR optimisation of Portfolio 3

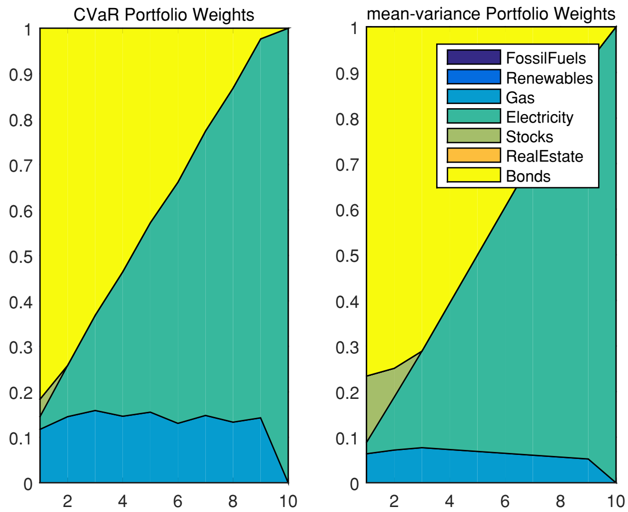


FIGURE 5.10: Weights Comparion for portfolios mean-variance and M-CVaR optimisation of Portfolio 3

To validate the results discussed above, Figure 5.9 illustrates the comparison of the weekly mean variance efficient frontiers of the MVO and the M-CVaR optimisation. We see in the figure that some small differences exist between the two optimisations, and this holds true especially for lower levels of portfolio returns. Generally, however, one can observe from Figure 5.9 that the results are significantly robust.

When comparing the weights of the two optimisations, we observe that using the M-CVaR optimisation invests in the same assets as the MVO, which are: Government Bonds, Gas, Electricity and Stocks. The allocation in certain assets differs as shown in Figure 5.10. In the M-CVaR optimisation more is invested in Gas and less in Stocks than the MVO portfolio weights. The reader is referred to Appendix A, which sets out the differences present in the first portfolios of the efficient frontier, and explains the differences of the frontiers in the lower level of return/risk ratio. However, since the results are analytically significant, we can confirm that an investor can still benefit even if she/he focuses on a single infrastructure sector.

Portfolio 4: Transport sub-sector assets (Airports, Ports and Toll Roads) within a traditional portfolio (e.g., Stocks, Real Estate and Government Bonds)

In our fourth and final considered portfolio, the diversification benefits gained are evaluated by investing only in the Transport sector. To this end, we construct a portfolio of only Transport sub-sector assets within a traditional portfolio. A multi-asset portfolio comprised of Transport sub-sectors, Stocks, Real Estate, and Government Bonds, a portfolio investment of 50.1% in Ports, 34.2% in Airports and 15.7% in Government Bonds, achieves a maximum Sharpe Index of 0.427.

Similar to the two previous optimisations, results are robust when carrying out the M-CVaR optimisation. When the two efficient frontiers are compared (Figure 5.11), we notice that the frontiers are similar, with the exception of small differences observed at the lower levels.

When we compare the allocation of the assets in the two optimisations in Figure 5.12, we can see that in the Mean-Variance portfolio, more weight is invested in Toll Roads and Stocks relatively, than to the CVaR Portfolio Weights. When we examine the efficient frontiers portfolios in Appendix A, we notice that the differences in the allocation of certain assets lie at the lower level of the risk/return

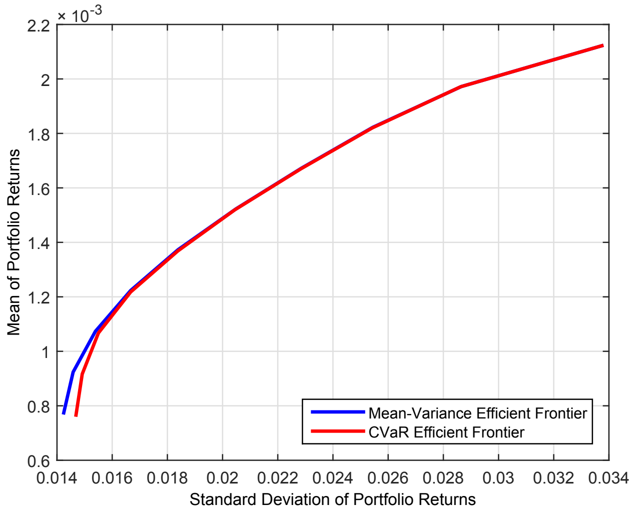


FIGURE 5.11: Efficient frontiers for portfolios mean-variance and M-CVaR optimisation of Portfolio 4

ratio. However, given the similarity of the results, we can once again confirm that investors can focus and invest in a single sector.

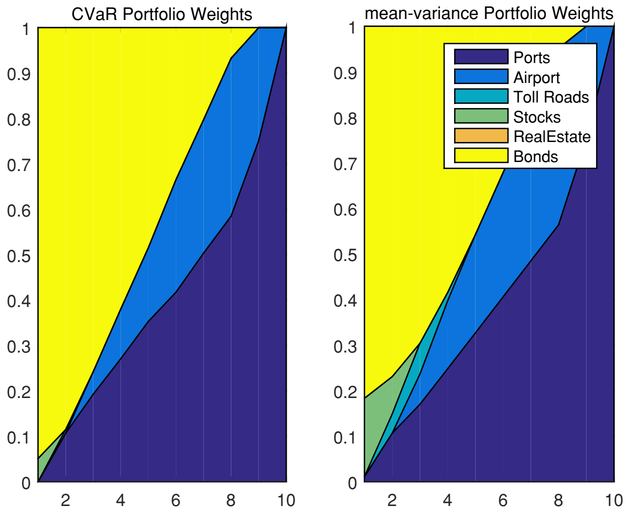


FIGURE 5.12: Weight Comparison for portfolios mean-variance and M-CVaR optimisation of Portfolio 4

5.5 Conclusions and Policy Implications

The importance of infrastructure to the economic welfare of countries is well-known among economists, governments and policy makers. The provision of good quality infrastructure is on the agendas of every European government because infrastructure investment leads to higher living standards, economic growth and a means of escaping the recession from which many European governments still suffer. However, the importance of infrastructure investment not only rests with governments that turn to infrastructure as a way to boost their economies: institutional investors are also paying close attention to infrastructure assets, particularly European ones. According to Preqin (2013a), from the 3700 infrastructure deals that took place since 2008, an annual average of 47% have been made using European assets.

But despite greater interest in European infrastructure assets, little research to date has examined the performance and portfolio implications of this asset class. The economic importance and investment characteristics of infrastructure have been studied mainly at the global level since the late 1980s, with scant analysis of different infrastructure sectors (Finkenzeller et al., 2010). As (Oyedele et al., 2013, p.3) have stated, infrastructure is an incorporation of many heterogeneous sectors including roads, bridges, ports, power generation, electricity, gas utilities, and telecommunications with no two having identical attributes.

Due to the importance of European infrastructure assets in the global context, and the existence of heterogeneity among different infrastructure sectors and sub-sectors, we set out in this chapter to evaluate the performance of different listed European economic infrastructure assets, e.g., Energy, Utilities, Telecoms, and Transport over a period that also captures the effects of the financial crisis. The present chapter has also provided a performance analysis of Energy and Transport sub-sector indices as a way to closely evaluate the behavioural differences and similarities of a selection of sub-sectors. The chapter has also examined the significance of including infrastructure in a mixed asset portfolio and has attempted to determine the best way to construct and invest in an infrastructure portfolio.

Our results for the European analysis indicate that infrastructure sectors and sub-sectors perform differently and show variations in annual returns and volatilities. In response, greater attention should be paid to specific infrastructure sectors. Not only is knowledge about the performance of different infrastructure sectors crucially important to fund managers, but so is knowledge about each sub-sector equally vital. It is important to focus and have a deeper knowledge of each infrastructure sector as each sector as this will enable the investor to identify the determinants that affect each sector in particular. For instance, energy markets are highly correlated with prices of commodities such as oil, gas, renewables while, on the other hand an airport's revenues are affected by the business model followed in that airport and the consumer or passenger experience. This is of particular importance in forecasting analyses where the fund manager must forecast the returns of its investments.

Findings in the second part of the analysis verify that when the infrastructure sector is combined with other traditional assets, the portfolio yields a higher Sharpe Index than the Sharpe Index to be gained by investing in any single asset. In this chapter we can conclude that investing in listed infrastructure is beneficial as long as it is a subset of a traditional portfolio. Furthermore, according to the present research, the creation of a portfolio that invests in different infrastructure sectors is never an optimal solution. For this reason, a sub-sector Transport and Energy portfolio analysis was performed, and through this analysis we have confirmed that there are indeed diversification benefits, even within a specific infrastructure sector.

The financial crisis of 2008 imposed constraints on the availability of public funds, such that limited available resources must be spent as efficiently as possible. Since that time, governments have had to select and prioritise among various infrastructure projects (Szimba and Rothengatter, 2012). The research carried out here has proved that by focusing on one listed infrastructure sector a fund manager can gain complete knowledge of the performance of the sector and still enjoy diversification benefits. An exciting policy implication of our finding is that if a country lacks investment in one particular sector, it can invest in this sector and still be able to diversify its infrastructure investment portfolio.

In chapter 6 all the portfolio analyses performed here will be repeated using two additional measures of risks as well as an out-of-sample analysis. All of the optimisations in this chapter have been conducted using in-sample analyses.

Chapter 6

Evaluating an infrastructure portfolio under different risk measures

6.1 Introduction

In the search for higher yields, institutional investors around the world are homing in on investment in alternative asset classes; infrastructure in particular is increasingly attracting the attention of institutional investors (RREEF, 2007).

Given the positive investor sentiment towards infrastructure investment, in this chapter, it is argued that the study of infrastructure in the portfolio context is vitally important for all institutional investors. It is true that many scholars have tested the effects of infrastructure in a portfolio (please refer to Chapter 2). However, this chapter aims to measure and predict infrastructure performance in a portfolio with greater accuracy in a sector having mostly small available datasets. Infrastructure assets, like other alternatives, exhibit the possibility of non-normal returns and the persistence of fat tail risks, making traditional risk techniques (such as volatility) unsuitable for capturing risk. Although financial experts acknowledge the challenges arising in the optimisation of listed infrastructure, to our knowledge only four scholars have thus far implemented alternative risk management methodologies (Bianchi et al., 2014, Dechant and Finkenzeller, 2012, Finkenzeller et al., 2010, Panayiotou and Medda, 2016). Due to scant available studies, investors have generally resorted to the allocation of a smaller proportion to infrastructure investment, compared to other alternative assets in their portfolios (Preqin, 2015).

As seen in Chapter 5, each infrastructure sector and sub-sector has its own performance profile, thereby raising different implications for the construction of infrastructure portfolios. Having constructed the portfolios in Chapter 5, in this chapter the portfolios are re-examined under different risk measures. Our aim here is to assess the performance of a portfolio investing in European listed infrastructure in terms of different trading strategies; and in so doing, evaluate which are the best performing infrastructure sectors when examined under different risk measures. Furthermore, in our extension of the single sector portfolio presented in Chapter 5, we also re-examine sector portfolios under different optimisation strategies.

Following Krokhmal et al. (2002), this chapter compares traditional optimisation techniques, such as the Minimum-Variance framework and the Minimum- Mean-Absolute Deviation (MAD), with the risk-management methodologies Minimum Conditional Value-at-Risk (CVAR) and Minimum Conditional Drawdown-at-Risk (CDaR). In summary, an in-sample analysis of the Mean-Variance Optimisation (MVO) and Mean-CVaR (M-CVaR) optimisation was carried out in Chapter 5. In the in-sample analysis in this chapter we include two more risks, the MAD and CDaR, which enable us to detect any differences in the optimal portfolios under the four different risk measures. An out-of-sample analysis is performed too, in our study of the performance and allocation of the optimal portfolio under four different optimisation strategies. By studying the infrastructure sector and sub-sector behaviour in the portfolio context under alternative optimisation techniques, we anticipate that investor confidence will increase in regard to achieving stable, lower risk long-term returns from infrastructure.

6.2 Data and research methodology

In addressing the objectives of this chapter we use the same historical times series of monthly EU returns data collected from Thomson Reuters Database over 11 years (2003-2013) for different infrastructure sectors, and weekly returns data collected for different infrastructure sub-sectors over 10 years (2004-2013). Indexes on traditional assets such as Stocks, Real Estate and Government Bonds are also used so that we may replicate an institutional portfolio.

Portfolio construction in this Chapter 5, takes place at both European level and at the European specialised sector level, however here, the portfolios are evaluated under four different trading strategies. The differences of each optimisation technique are first examined using an in-sample analysis for the whole dataset. The examination of the in-sample analysis is done by observing the efficient frontiers of each different risk measure in each return/risk space. In this endeavour four different graphs are developed, each accounting for a different risk, thereby presenting the risk/return performance of the four efficient frontiers. To better understand the differences between the optimisations, the portfolio configurations for each risk objective are depicted in area graphs showing the allocation of the assets in the in-sample analysis.

Our second test in this analysis is to repeat the optimisations using an out-of-sample analysis. With the results of the in-sample analysis, an investor would be expected to pick up any portfolio on the efficient frontier. However, to do so, investors would have to assume that similar returns will repeat in the future. Following Krokhmal et al. (2002), we perform an out-of-sample analysis, where part of the data is used for scenario generation and the remainder is used to evaluate the results of the four optimisations by examining the performance of each strategy. The out-of-sample analysis is more important than the in-sample analysis in that it provides empirical information on the actual performance of the optimisation techniques. To perform the out-of-sample analysis we use the first year of the dataset as the in-sample data for constructing the first portfolio to build into. Investors are assumed to be highly risk-averse so they aim for the portfolio that gives the minimum risk. After determining the allocation of the weights the portfolio value can be calculated. This process is repeated every quarter, rebalancing the portfolio for the whole dataset, thereby accumulating the in-sample data for scenario generation with every quarter.

To our knowledge, the only out-of-sample analysis on infrastructure portfolios was carried out by (Dechant and Finkenzeller, 2012, 2013). Using an out-of-sample analysis enables us to determine which strategy will perform best and what will be the efficient infrastructure sector and sub-sector allocation over time. The analysis of the MVO and CVaR optimisation is repeated for a non-risk averse investor to examine how listed infrastructure sectors and sub-sectors relate to investors' risk preferences. In order to avoid concentration on any single asset, the weight constraints for each asset are $0 \leq x_I \leq 0.8$.

6.3 Results

In this section we analyse three different portfolios:

- Portfolio 1 includes European infrastructure sectors (Energy, Telecoms, Utilities and Transport) along with traditional assets (Stocks, Real Estate and Government Bonds).
- Portfolio 2 specialises only in Transport sub-sector assets (Airports, Ports and Toll Roads) within a traditional portfolio.
- Portfolio 3 specialises only in the Energy sub-sector assets (Natural Gas, Electricity, Fossil Fuels, and Renewable Energy) within a traditional portfolio.

6.3.1 In-sample analysis

Portfolio 1: Constructing a portfolio that invests in traditional assets and European infrastructure sectors

The first portfolio examined in the in-sample analysis invests in traditional assets such as Stocks, Real Estate and Government Bonds along with infrastructure sectors: Energy, Telecoms, Utilities and Transport. The portfolio is optimised using MVO, M-CVaR, M-CDaR, MAD optimisation techniques, and efficient frontiers of each optimisation are depicted in Figure 6.1.

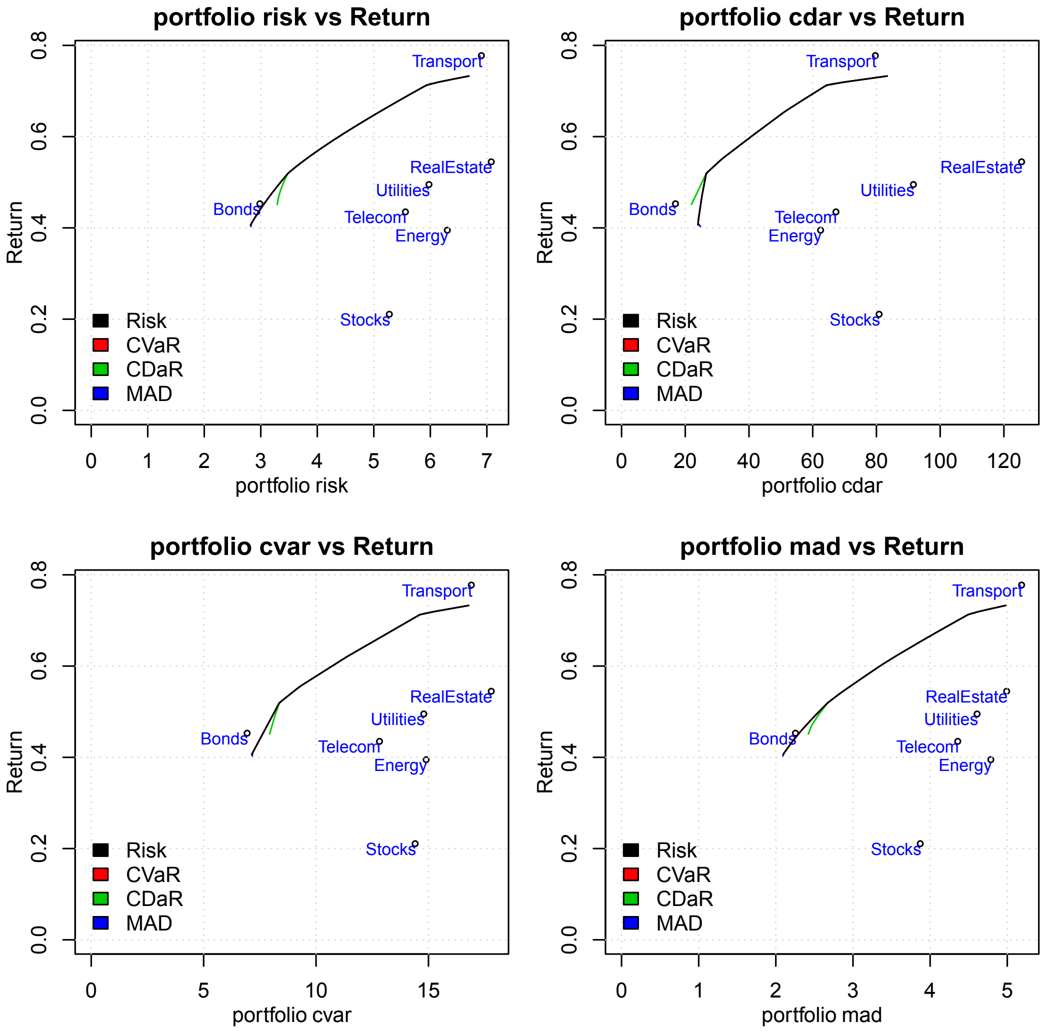


FIGURE 6.1: Efficient Frontiers showing Risk/Return in % for the mean-variance, M-CDaR, M-CVaR and MAD optimisation for Portfolio 1

The first graph in Figure 6.1, gives the efficient frontier of each risk objective using the standard deviation of the optimal portfolios as a measure of risk (referred here as risk because this traditional risk measure is used in both academia and industry); the second graph depicts all the efficient frontiers using the portfolio CDaR as a risk measure; the third graph shows all four efficient frontiers using portfolio CVaR as a risk measure; and lastly, the fourth graph uses portfolio MAD as a risk measure. Figure 6.1 also examines the single assets in all of the different risk spaces. In this examination we advocate that, importantly, individual assessment should be done in each infrastructure sector because they produce different risk profiles. It is noteworthy that, under traditional risk measures such as volatility and MAD, infrastructure sectors have higher risk than stocks, but lower than real estate. However, under downside risks measures such as the CVaR and CDaR, we notice that all infrastructure sectors perform better, particularly on a risk-adjusted basis. This is true for all infrastructure sectors; thus, the implication here is that it would be optimal for investors to re-allocate their weighting of real estate and equities into certain infrastructure sectors.

When performing the optimisations, we can see in Figure 6.1, that the efficient frontiers in each risk measure are very similar with only minor differences in the CDaR optimisation at lower levels of risk. Readers are referred to Appendix B Tables B.1 to B.4, for details on the differences present in the four portfolios of the efficient frontiers.

Next, Figure 6.2 sets out the allocations of the assets in the in-sample analysis. As with the efficient frontiers, the allocation of the assets is also very similar. The MVO, CVaR and MAD analysis invest in the same assets: Transport, Bonds, Real Estate, and Stocks. The weight of the allocation for each asset is also similar, with minor differences at the lower and upper levels of risk. On the other hand, the CDaR optimisation illustrates differences in asset allocation at lower levels of risk. Specifically, rather than Stocks, the CDaR optimisation invests in Telecom. The allocation of the optimal portfolio into infrastructure along with government bonds indicates the dominance of certain listed infrastructure sectors over real estate and stocks under all different optimisation techniques, confirming industry claims that listed infrastructure outperforms the equity market (CBRE, 2014).

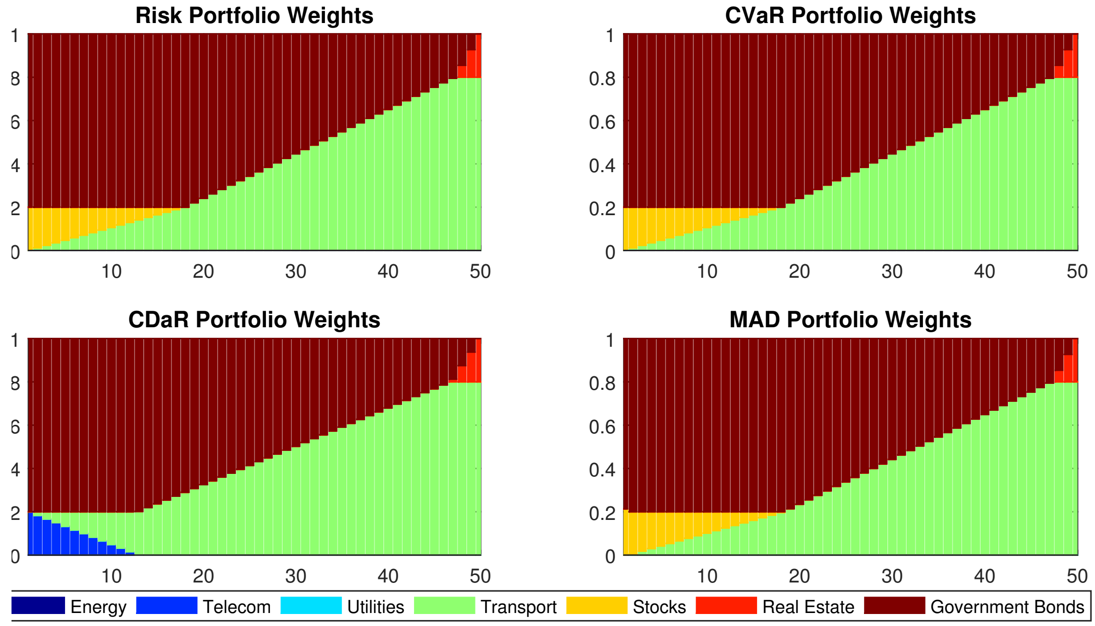


FIGURE 6.2: Weights comparison for portfolios mean-variance, M-CDaR, M-CVaR and MAD optimisation of Portfolio 1

Portfolio 2: Constructing a portfolio that invests in European Transport sector

We next present an in-sample analysis of a portfolio focusing in Transport. When examining different Transport sub-sectors under different levels of risk, we can observe in Figure 6.3 that all Transport sub-sectors illustrate lower risk profiles than real estate. In relation to stocks, under traditional risk measures (volatility and MAD), ports and toll roads have a slightly higher risk profile than stocks but at the award of higher returns. Conversely, airports show a closely similar risk profile to stocks, but airports offer a higher return than the rest of the equity market. When examining transport assets under downside risk measures such as CDaR and CVaR, similar observations are made; airports are seen to have lower risks and higher return than stocks, ports are seen to have higher downside risks; however, these higher risks are accompanied by higher returns. Toll roads have only marginally higher downside risks than Stocks but they offer a higher return as well. The heterogeneity of infrastructure sub-sectors makes it abundantly clear that infrastructure behaves differently, even within a single sector. Therefore, it should not, under any circumstance, be seen as a single homogenous asset.

When comparing the efficient frontiers of the four optimisations we can again observe that the optimisations that used variance, MAD and CVaR as risk, produce almost identical efficient frontiers. However, the CDaR optimisation produces a different efficient frontier than the other three optimisations.

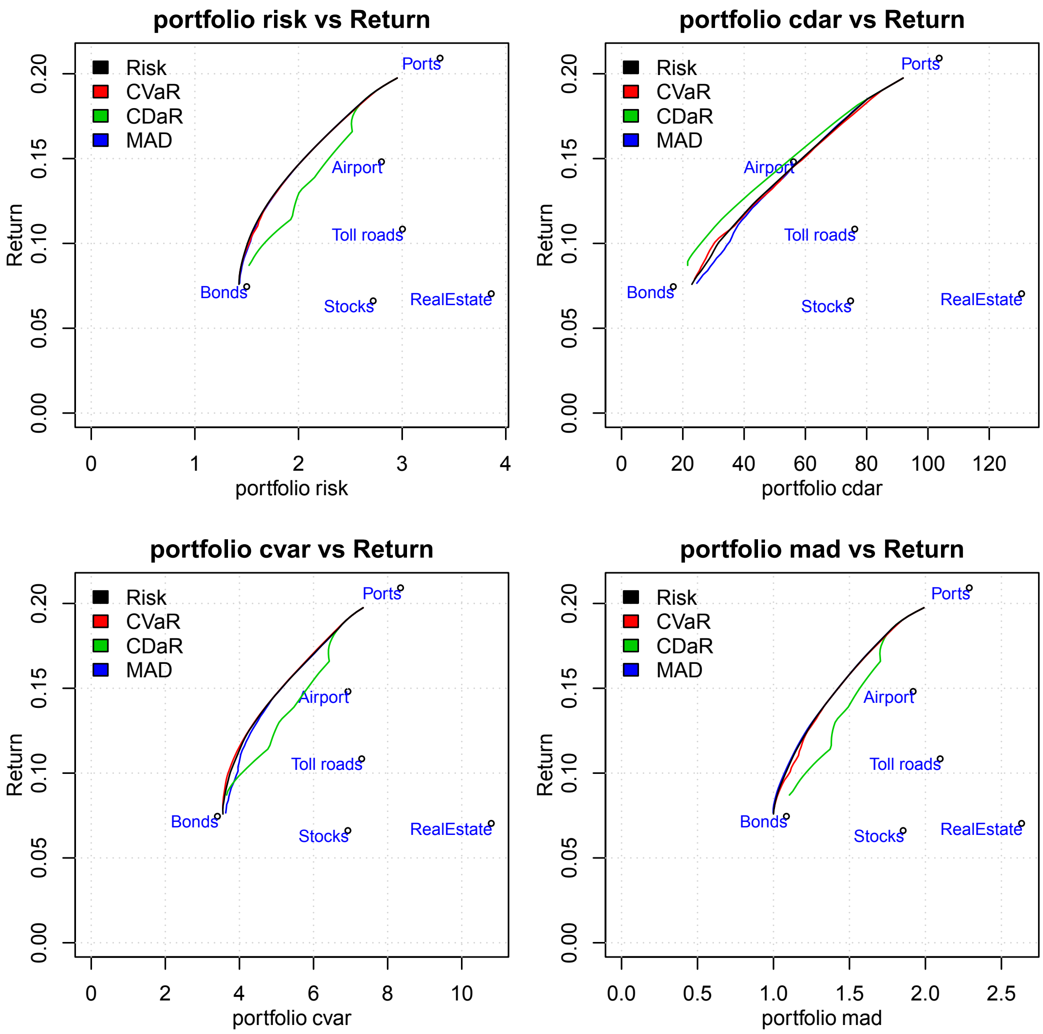


FIGURE 6.3: Efficient Frontiers showing Risk/Return in % for the mean-variance, M-CDaR, M-CVaR and MAD optimisation for Portfolio 2

To observe the differences in the allocation of the optimisations, readers are referred to the Figure 6.4. When optimising an infrastructure Transport portfolio, we reach similar results to those found in Chapter 5. We can see that in the MVO, M-CVaR, M-CDaR, and MAD optimisations all portfolios allocate mainly into Airports, Ports and Government Bonds with some allocation to stocks and toll roads at lower levels of risk.

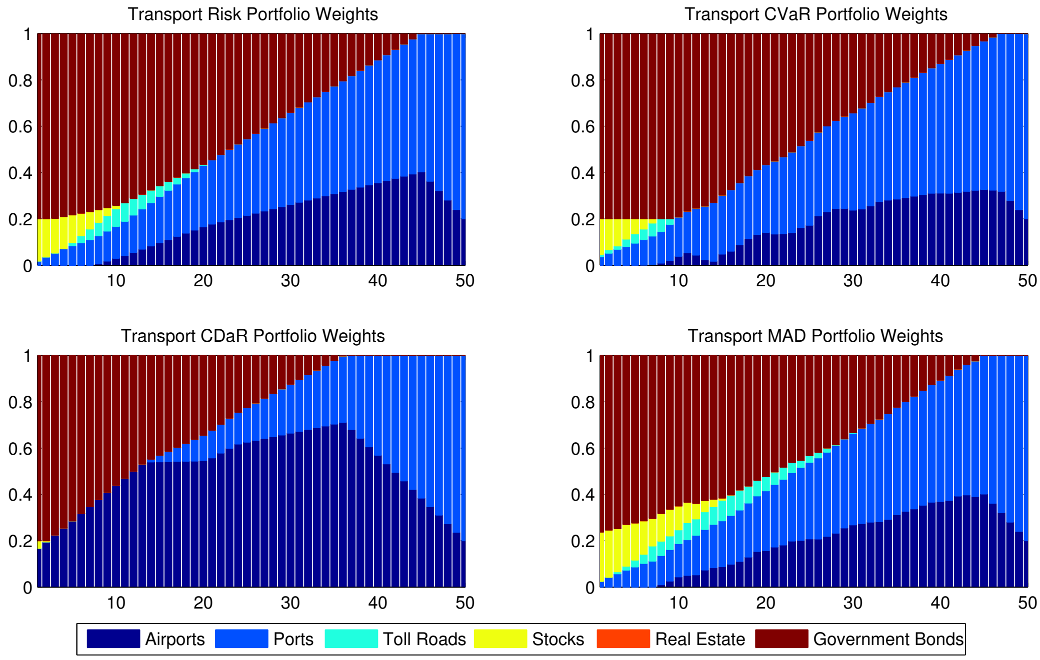


FIGURE 6.4: Weights comparison for portfolios mean-variance, M-CDaR, M-CVaR and MAD optimisation of Portfolio 2

Portfolio 3: Constructing a portfolio that invests in European Energy sector

In this section, we examine the in-sample analysis of a portfolio investing only in Energy. In relation to the risk profile of each energy sub-sector, we observe in Figure 6.5 that under all risks, electricity and natural gas perform better than stocks and real estate, both in terms of returns and risks. On the other hand, renewable energy is seen to be the worst asset in terms of risk/return performance under all four risk frameworks. This is not surprising to us, as these are new investments that entail great uncertainty, given the political risks they carry. We expect, however, that their performance will gain momentum in the future in the face of the EU 2020 regulations to decrease CO_2 emissions. Governments will be forced to fine-tune their regulations accordingly in order to attract more private investments in renewables. Fossil Fuels are also seen to perform worse than Equity and Real Estate on a risk-adjusted basis under all risk measures. This examination again illustrates the high differences that exist among the sub-sectors of a single infrastructure sector.

The efficient frontiers of each optimisation, as seen in Figure 6.5, do not illustrate any substantial differences. Consistent with our findings in Chapter 5, the asset allocations in Figure 6.6 indicate that the optimal portfolios allocate in stocks, electricity, natural gas, and government bonds; we can therefore verify that constructing an investment portfolio comprised only of Energy can still be beneficial.

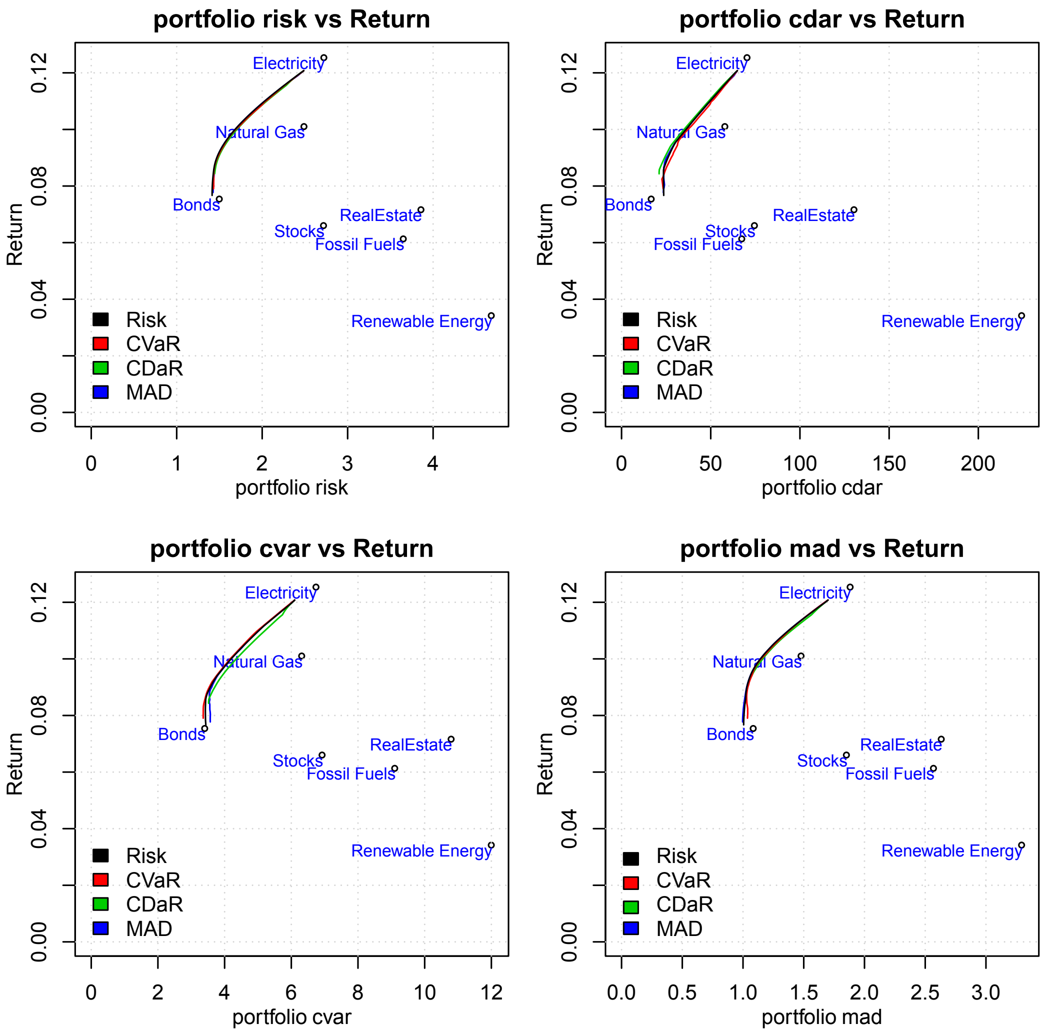


FIGURE 6.5: Efficient Frontiers showing Risk/Return in % for the mean-variance, M-CDaR, M-CVaR and MAD optimisation for Portfolio 3

We notice too, as in our previous observations, that it is optimal to re-allocate the weightings of the Stocks and Real Estate allocation into infrastructure energy sub-sectors, particularly to obtain medium-to-high levels of portfolio returns. The implication here is that, for medium risk-averse investors, there are certain infrastructure sub-sectors that offer better risk protection for a given return relative to other traditional assets (see Appendix B). Whereas, in the CDaR portfolio investment of two Energy sub-sectors (Electricity and Natural Gas) and Government Bonds, it is only optimal for high risk-seeking investors, as the efficient frontier at the upper end of Figure 6.5 confirms.

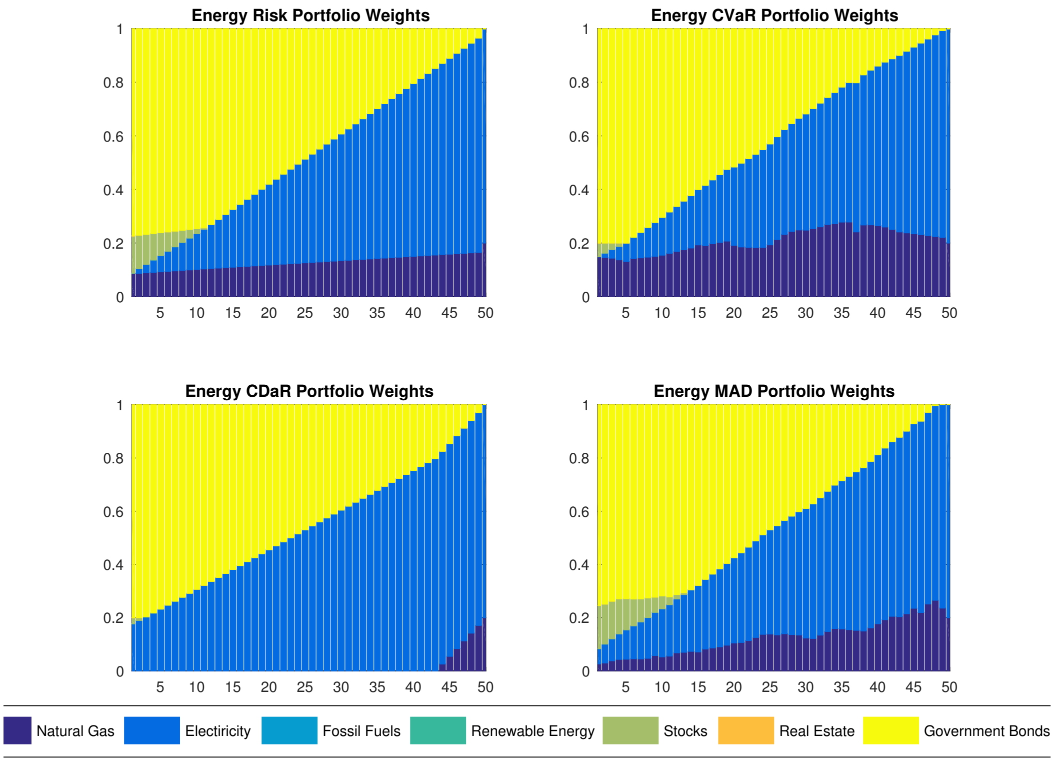


FIGURE 6.6: Weights comparison for portfolios mean-variance, M-CDaR, M-CVaR and MAD optimisation of Portfolio 3

6.3.2 Out-of-sample analysis

Portfolio 1: Constructing a portfolio that invests in traditional assets and European infrastructure sectors

In this section, we re-examine a portfolio investing in European listed infrastructure sectors along with traditional assets using an out-of-sample analysis. The performance of the optimal portfolio under the Minimum CVaR (min.CVaR) and Minimum CDaR (min.CDaR) techniques is clearly superior to the Minimum-Variance (min.Risk) and Minimum MAD (min.MAD) optimisations in terms of cumulative returns. To enable the comparison of the four trading strategies in terms of risks as well, in Table 6.1, the Sharpe ratio and various other risk measures are calculated for each of the four optimal portfolios. The outperformance of the min.CVaR and min.CDaR on a risk-adjusted return basis is illustrated clearly, as the two trading techniques show a higher Sharpe ratio for the whole period tested. In terms of riskiness, the min.CVaR optimisation shows lower risk than the min.CDaR and min.MAD optimisation. However, the lowest risks are presented by the minimum variance (min.risk) portfolio. In terms of a risk-adjusted performance, however, the min.CVaR optimisation clearly outperforms all other trading strategies.

What interests us most in this section is our analysis of the allocation of the assets at different times during the whole period (2004-2013) across the four different trading strategies. In the in-sample analysis we saw that including infrastructure in the portfolio is optimal under all four different risks. In the out-of-sample analysis the optimal portfolio is the portfolio that minimises risk. We can now examine whether it is optimal to include infrastructure in the portfolio for a highly risk-averse investor. When we turn to Figure 6.8 we conclude that in the minimum risk portfolio infrastructure assets are not an optimal strategy. This holds true particularly for the min.MAD and min.Risk portfolio, where there is no allocation in infrastructure assets. Whereas for the min.CVaR and min.CDaR portfolios it is optimal to invest in infrastructure sectors in the early years of the data sample.

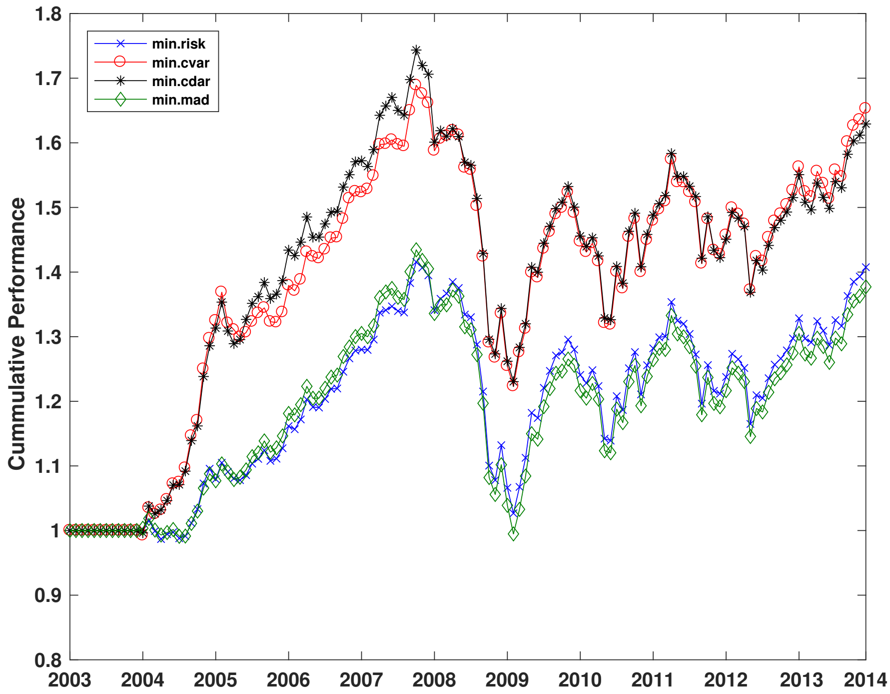


FIGURE 6.7: Historical trajectories of optimal portfolios with various risk constraints of Portfolio 1

Table 6.1: Portfolio 1: Comparison of each model's performance

	min.cdar	**min.cvar**	**min.mad**	**min.risk**
Sharpe Ratio	0.52	0.54	0.37	0.39
Annual Volatility	9.49%	9.34%	9.01%	8.88%
MaxDD	-29.43%	-27.58%	-30.65%	-27.47%
AvgDD	-4.71%	-4.54%	-4.60%	-4.20%
VaR	-5.59%	-4.78%	-4.94%	-4.44%
CVaR	-6.73%	-6.59%	-6.54%	-6.51%

However, this is expected to change if instead of choosing to hold the minimum risk portfolio we are willing to accept higher risk for higher returns. To test this expectation, we repeat the out-of-sample analysis for the M-CVaR and MVO optimisation. But this time in the M-CVaR optimisation 10 optimal portfolios are constructed, and the median (5^{th} portfolio) is chosen as the optimal portfolio. In the MVO optimisation, the optimal portfolio is the one that maximises the Sharpe ratio. In Figure 6.9, when using the portfolio that maximises the Sharpe ratio as the optimal portfolio instead of the minimum variance portfolio, listed infrastructure sectors become the favourable choice over the stock market. This sends the message to investors, who are not highly risk-averse, that certain listed infrastructure sectors are an optimal choice in their asset allocation decisions. And when comparing the M-CVaR optimisation with the MVO optimisation, in cases where our risk-objective is to minimise CVaR with a specific target return, we can verify higher allocations to infrastructure indices.

Figure 6.9 depicts that, in the M-CVaR optimisation, allocations to infrastructure indices increase substantially. The comparison shows that infrastructure assets have lower tail risks and offer better downside protection than stocks, confirming the assertions made by Adam (2013). This was also demonstrated in Bianchi et al. (2014), where they concluded that even though the differences of the tail-risk statistic among US listed infrastructure and stocks were negligible, they were nevertheless sufficient for the optimal portfolio to switch from US stocks to allocations of more listed infrastructure. However, in the present study of European infrastructure, this effect is specific only to specific infrastructure sectors, e.g., Transport and Utilities, and for investors aiming to hold an optimal portfolio in the medium-to-upper levels of the efficient frontiers.

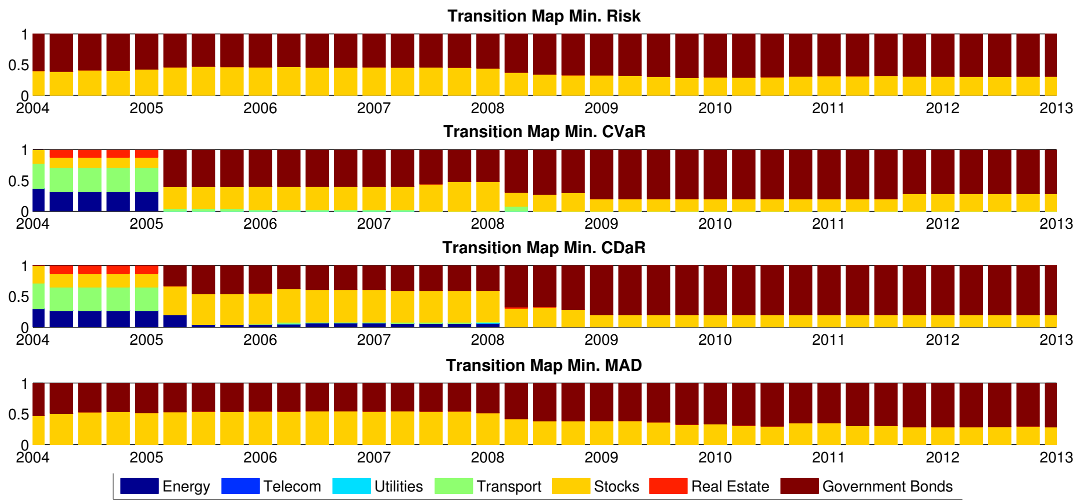


FIGURE 6.8: Transition maps for portfolios under various risk constraints of Portfolio 1

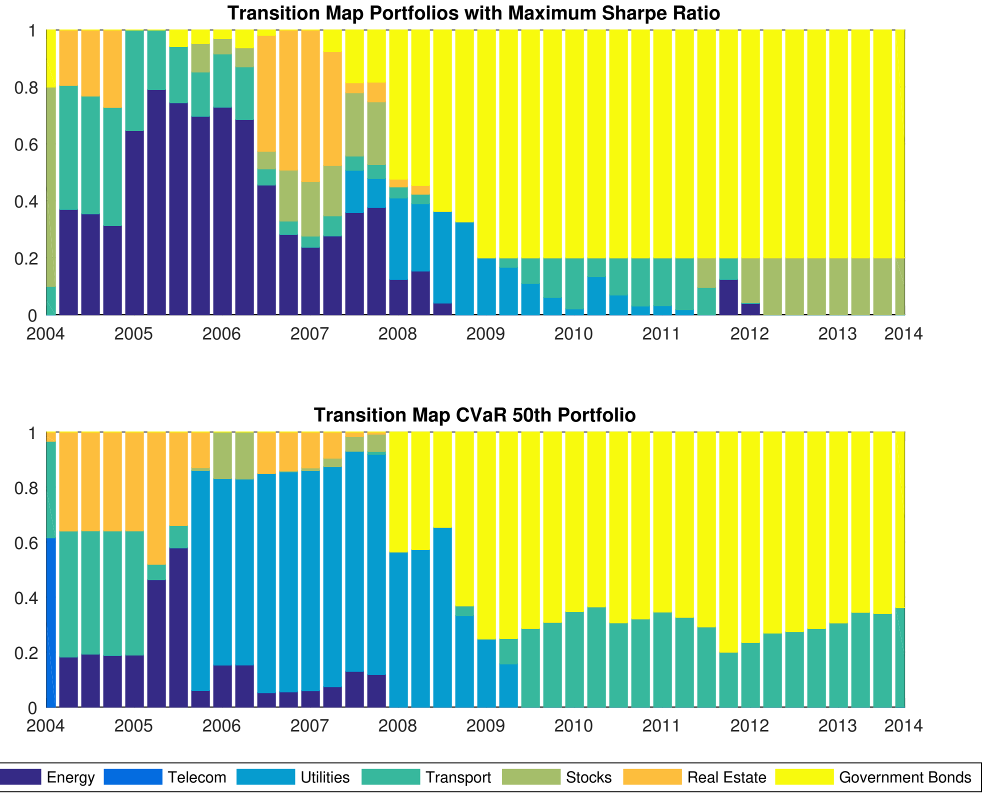


FIGURE 6.9: Transition maps for portfolios of a non-risk averse investor of Portfolio 1

Portfolio 2: Constructing a portfolio that invests in Transport sector along with traditional assets

In this section, a portfolio where an investor focuses only in transport assets along with traditional assets is examined using an out-of-sample analysis. In figure 6.10 of the European sector analysis, the min.CVaR trading strategy has a higher cumulative performance than all other strategies in the portfolio. However, contrary to the previous analysis, the min.CDaR optimisation does not outperform the min.MAD and min.Variance optimisation. In terms of Sharpe ratios, seen in Table 6.2, the CVaR trading strategy has the highest Sharpe ratio of all. In terms of risks, apart from Value-at-Risk (VaR), we observe that the min.MAD and min.Risk portfolio offer lower volatility as well as lower downside risks.

Our exercise of comparing the allocation of Transport assets among the four trading strategies has yielded interesting results. From Figure 6.11, we notice that the

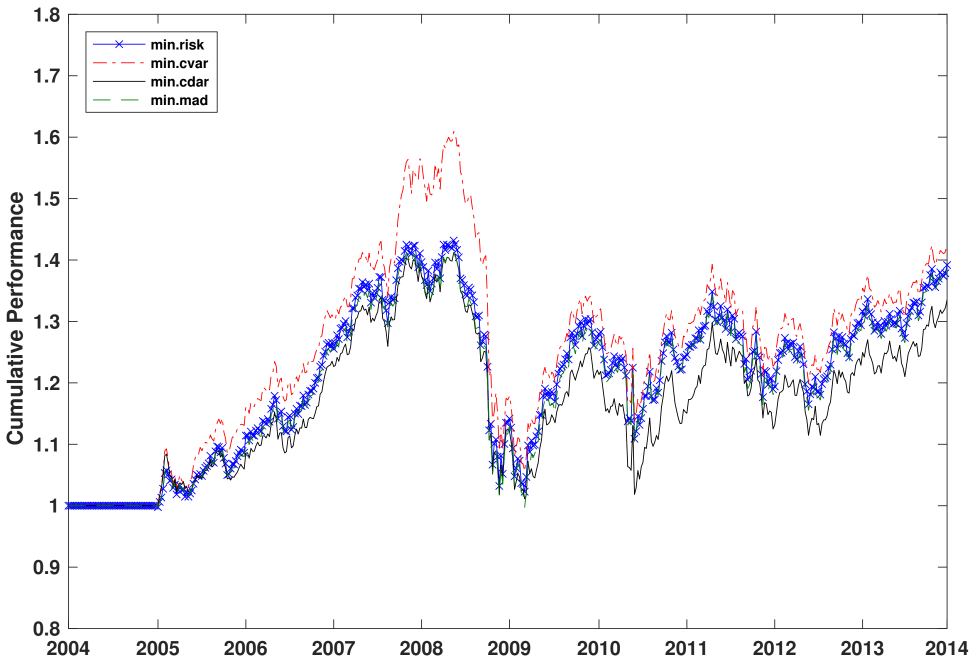


FIGURE 6.10: Historical trajectories of optimal portfolios with various risk constraints of Portfolio 2

Table 6.2: Portfolio 2: Comparison of each model's performance

	min.cdar	**min.cvar**	**min.mad**	**min.risk**
Sharpe Ratio	0.33	0.38	0.37	0.37
Annual Volatility	10.60%	10.91%	10.37%	10.34%
MaxDD	-28.36%	-34.39%	-29.40%	-28.56%
AvgDD	-3.67%	-3.28%	-2.95%	-2.70%
VaR	-2.22%	-2.11%	-2.19%	-2.14%
CVaR	-3.60%	-3.85%	-3.72%	-3.66%

two optimisations that invest more in infrastructure sub-sectors are the min.CVaR and min.CDaR optimisations. Nevertheless, even with the traditional techniques (min.Risk and min.MAD) we see significant allocation in toll roads. It is worth repeating that the optimal allocations shown in Figure 6.11 assume investors to be highly risk-averse and intent upon holding the minimum risk portfolio.

However, when investors are willing to accept more risk for more return we expect increases in infrastructure allocations in the optimal portfolio at the expense of fewer stocks. To test this, we repeat the out-sample analysis of the MVO optimisation and M-CVaR optimisation, taking as the optimal portfolio that which maximises the Sharpe ratio in the MVO optimisation and the median portfolio of the M-CVaR optimisation. Results in Figure 6.12 are in line with our expectations: for more risk-seeking investors, the more dominant strategy is to invest more in certain listed infrastructure sectors, not traditional assets. This is clearly illustrated in both the MVO and M-CVaR optimisations. In the MVO optimisation when our strategy is to hold the minimum variance portfolio, the optimal choice is to invest in toll roads, stocks and government bonds. However, when our optimal strategy in the portfolio is to maximise the Sharpe ratio, it is most efficient to invest in all listed infrastructure sectors, with a small proportion in stocks and government bonds. Similarly, in the M-CVaR optimisation, when assuming a non-risk averse investor, the optimal strategy is to invest more in listed infrastructure sectors, and less in stocks. We can therefore confirm that the investor can construct a portfolio focusing on a single infrastructure sector. In addition, when we compare the MVO and M-CVaR optimisations, similar to our previous conclusions, the M-CVaR strategy invests more in infrastructure than the MVO.

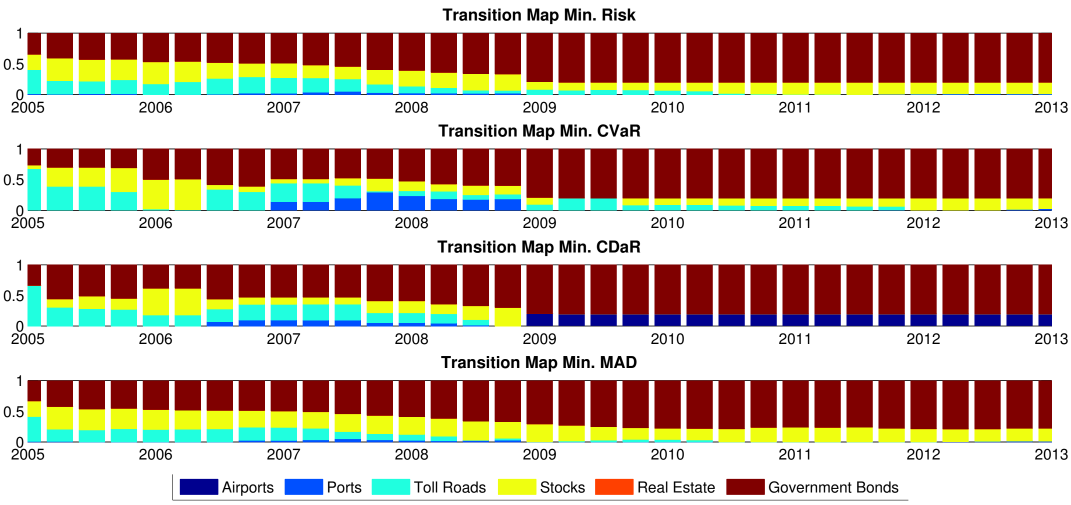


FIGURE 6.11: Transition maps for portfolios under various risk constraints of Portfolio 2

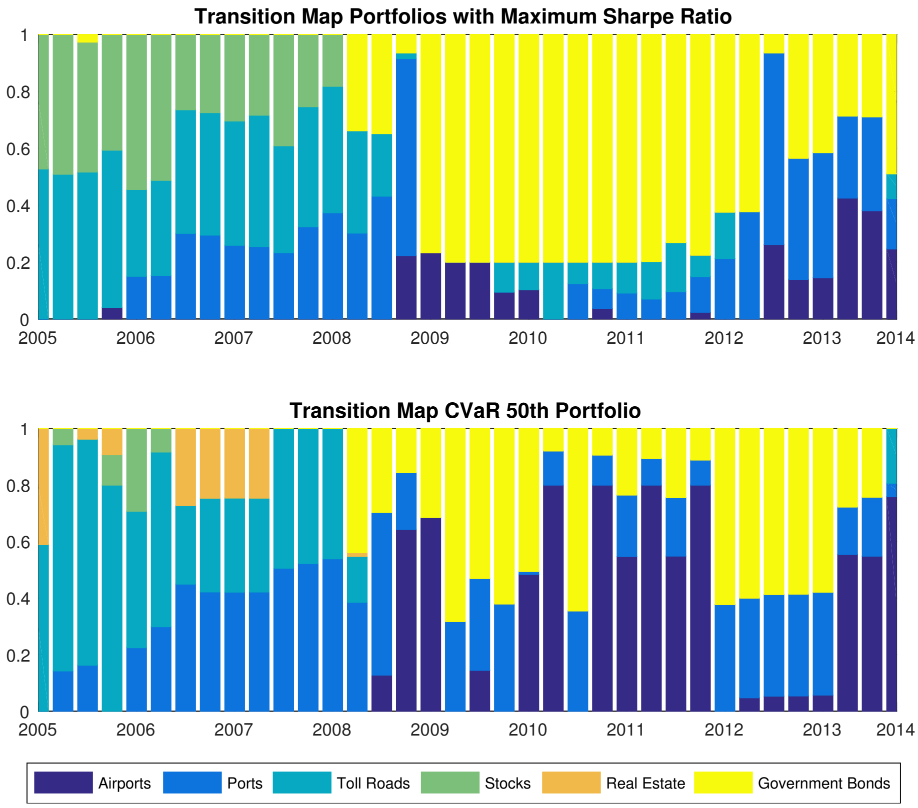


FIGURE 6.12: Transition maps for portfolios of a non-risk averse investor of Portfolio 2

Portfolio 3: Constructing a portfolio that invests in Energy sector along with traditional assets

For the energy sector we can again observe out-performance of the min.CVaR trading strategy. In the Energy portfolio CVaR shows better returns and lower risk measures across all examined risks. The min.CDaR portfolio has a Sharpe ratio similar to traditional optimisation techniques and, even though in regard to tail risk the CDaR optimisation presents lower tail risks than optimal portfolios of traditional optimisation techniques, it also shows higher volatility and higher average drawdown.

As can be seen from the transition maps of all trading strategies in Figure 6.14, it is optimal to invest in the electricity sector across the whole data, which shows the outperformance of the electricity sector to both stocks and real estate. The two downside risk optimisations invest only in government bonds, infrastructure

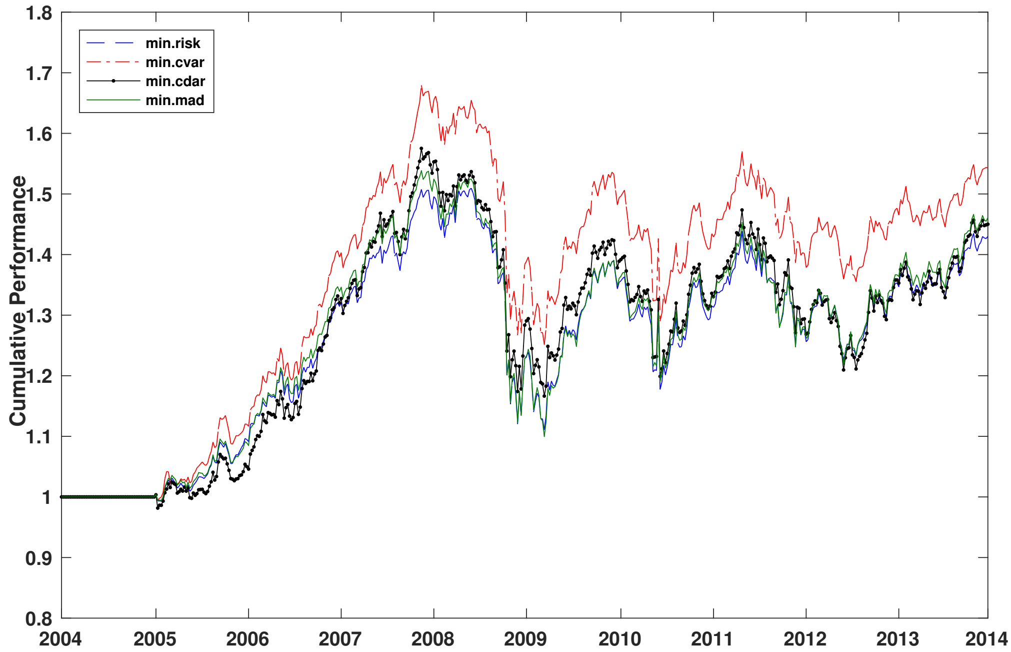


FIGURE 6.13: Historical trajectories of optimal portfolios with various risk constraints of Portfolio 3

Table 6.3: Portfolio 3: Comparison of each model's performance

	min.cdar	**min.cvar**	**min.mad**	**min.risk**
Sharpe Ratio	0.42	0.48	0.43	0.41
Annual Volatility	10.43%	10.12%	10.39%	10.18%
MaxDD	-25.95%	-25.48%	-28.52%	-26.40%
AvgDD	-2.84%	-2.50%	-2.57%	-2.34%
VaR	-2.16%	-1.95%	-2.20%	-2.10%
CVaR	-3.50%	-3.45%	-3.67%	-3.57%

sectors with very small allocations to real estate and stocks. Thus, one can confirm the dominance of certain infrastructure Energy sub-sectors to traditional assets.

As with the European and Transport portfolios, we expect that the allocation to infrastructure will increase as we move across the efficient frontier and willingness increases to hold a portfolio offering better returns in exchange for higher risks. The results indicate that when an investor is not highly risk-averse it is optimal to invest in all listed infrastructure sectors and less in traditional assets. Accordingly, this conclusion confirms yet again that an investor can invest in a single infrastructure sector and benefit from gaining a deep understanding of the sector.

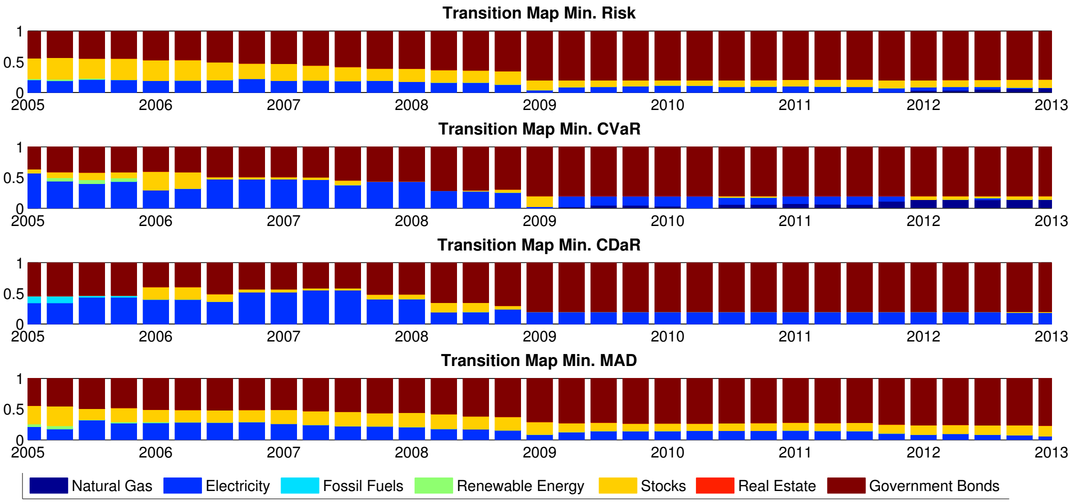


FIGURE 6.14: Transition maps for portfolios under various risk constraints of Portfolio 3

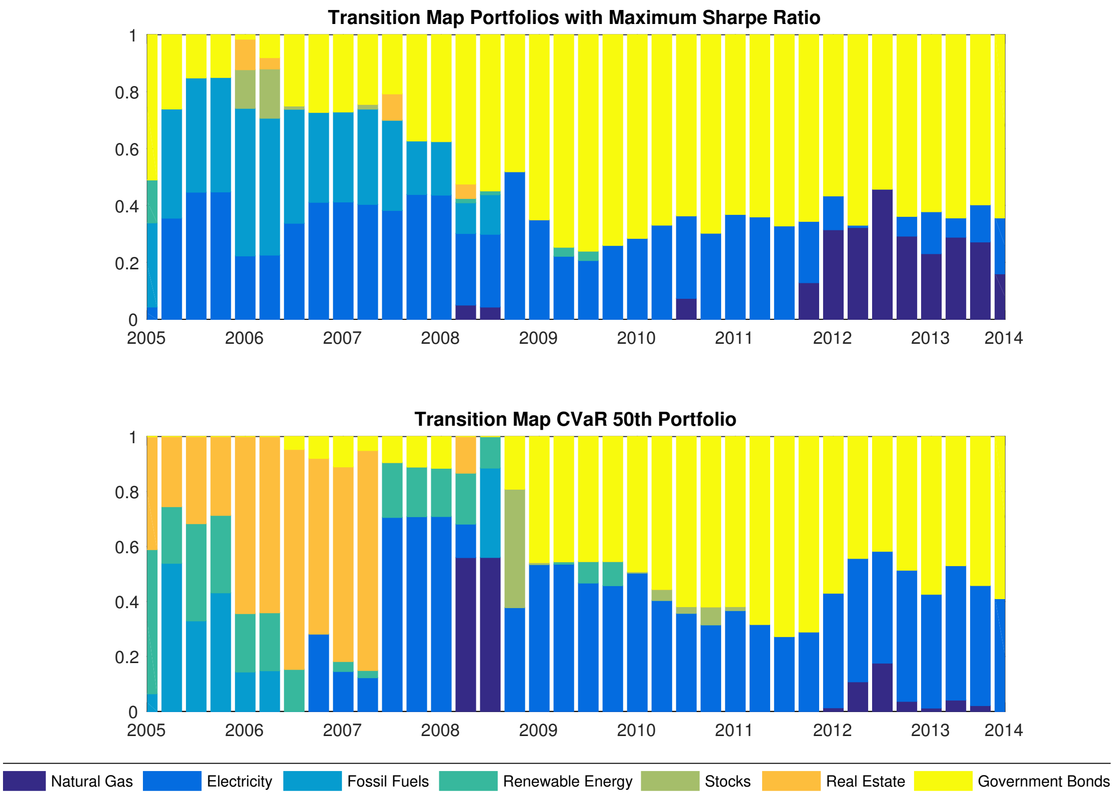


FIGURE 6.15: Transition maps for portfolios of a non-risk averse investor of Portfolio 3

6.4 Conclusion

Investors are undeniably paying closer attention to alternative investments such as infrastructure (Preqin, 2015). Listed infrastructure in particular is attractive to investors because it provides a combination of the unique characteristics of direct infrastructure along with the growth of the equities market. Investment opportunities in infrastructure are likely to reach funding requirements of trillions of dollars, and investors should be further encouraged to invest in this asset class.

Importantly, scant datasets and the possibility of non-normality of the distribution (Dechant and Finkenzeller, 2012) make traditional portfolio techniques unsuitable for constructing a portfolio with infrastructure. In response, this chapter has examined the infrastructure portfolio using a variety of optimisation techniques. The results for the in-sample analysis confirmed our findings in Chapter 5: that not only is infrastructure likely to benefit an institutional portfolio but it is also optimal to specialise and concentrate in single infrastructure sectors. The in-sample analysis of all four risk objectives produced relatively similar portfolio structures. Conversely, in our out-of-sample analysis, portfolio performance improved in terms of risk-adjusted returns when risk management techniques such as CVaR were introduced. Our findings are encouraging; infrastructure assets are optimal when included in the portfolio but they are particularly suited for investors who are not highly risk-averse. In other words, we verified that listed infrastructure returns offer better risk-adjusted returns by enhancing the returns of the portfolio rather than decreasing its risks. Last but not least, we can safely argue that investing in a single infrastructure sector can still provide an optimal strategy for investors given that they can invest in several sub-sectors and benefit from diversification as well as by gaining deep knowledge of a specific sector. Gaining knowledge on the sector can help the fund manager identify which factors affect that particular sector and the commodity prices and services that he needs to track in order to forecast the performance of the sector in the future.

Chapters 5 and 6 focused on European infrastructure. We conclude that the inclusion of European listed infrastructure in a traditional portfolio should be attractive for institutional investors as a way to add value to their portfolios. Furthermore, our analysis showed that understanding the specificity of each infrastructure sector and guiding the management of investors' portfolios are certainly the first steps towards greater participation in the financial system and to an innovative approach of finance which is at the service of main societal challenges.

We will next shift away from the European market and conduct a similar analysis as in Chapter 5, but in Chapter 7, we focus at country level: the United Kingdom infrastructure market. In Chapter 7 we look into the differentiation of UK infrastructure sectors and their roles in the institutional portfolio. By doing so we aim to enrich the research done in a significant infrastructure market such as the UK, where despite being such an important infrastructure market, it has only limited research to show for it.

Chapter 7

Portfolio of Infrastructure Investments: Analysis of United Kingdom Infrastructure

7.1 Introduction

In Chapter 5, we understood from the analysis how listed European infrastructure should be treated when constructing a portfolio of infrastructure investments. In this chapter we repeat a similar analysis, but at the country rather than regional level. In this Chapter, the aim is to repeat a similar analysis, however, at the country level rather than the regional level. As mentioned in Chapter 1, the UK along with Australia is the only two countries to have experienced early privatisation of its infrastructure investments. According to Infra Deals, the United Kingdom represents one of the world's most mature and appealing infrastructure markets for private investment (Infra Deals, 2016*a*). Private investment continues apace in the UK, and these investors are playing a critical role in the development of the country, in that mostly private finance is financing new greenfield projects and also upgrading existing infrastructure assets, particularly in the transport and utilities sectors (Infra Deals, 2016*a*). Furthermore, as we saw in Chapter 4, the government is trying hard to increase the attractiveness of infrastructure investments to the private sector.

But despite all these efforts, only one research (Oyedele, 2014) focuses on and examines the characteristics of UK infrastructure. For this reason, in this chapter we study the differences between the listed infrastructure sectors within the UK and reach conclusions on which sector is most lucrative in a portfolio of infrastructure investments.

7.2 Data and research methodology

As in Chapter 3, the author uses data collected from Thomson Reuters Database to address our two objectives. The date include historical time series of monthly returns of UK indices over a time span of 11 years (2003-2013) for different infrastructure sectors and traditional assets.

The study of UK infrastructure asset performance follows the exact lines of analysis developed in Chapter 5. The author compares the sectors using the annualised return, annualised volatility and Sharpe Ratio (Equation 5.1) of each index for the whole period (from Q1.2003 to Q4.2013). Diversification benefits among infrastructure sectors and with other traditional assets are evaluated using a correlation matrix and rolling correlation graphs. The effect of the financial crisis on the infrastructure sectors is captured by contracting our datasets to Q4.2007-Q2.2009. Similar to Chapter 5, the annualised return, annualised volatility and Sharpe Ratio are re-calculated for this 3-year period to examine the robustness of listed infrastructure sectors. In our second objective here, to determine the best way to construct a portfolio that invests in infrastructure, the author performs a portfolio historical analysis using the standard Markowitz (1952, 1959) Mean-Variance portfolio Optimisation (MVO) technique, as described in Chapter 3. As a robustness test the portfolio is repeated using the Conditional Value-at-Risk (CVaR) framework described thoroughly in Chapter 3.

Table 7.1: Historical Performance Analysis of UK Infrastructure Sectors for Period Q1.2003-Q4.2013

United Kingdom listed asset	Annualised Return	Annualised Volatility	Sharpe Index	Rank
Energy	3.30%	19.61%	0.096	6
Telecom	6.88%	17.14%	0.319	3
Utilities	4.99%	23.99%	0.149	5
Transport	8.90%	23.43%	0.320	2
Stock	5.82%	14.02%	0.314	4
Real Estate	3.65%	22.81%	0.098	7
Government Bonds	4.76%	8.65%	0.388	1

7.3 Results

United Kingdom Infrastructure sector performance analysis

Table 7.1 shows the performance of United Kingdom assets for the period 2003-2013. The four listed infrastructure sectors show significant variation, confirming the conclusions from our European sector analysis: infrastructure should not be treated as one asset, instead attention should be paid to each infrastructure sector.

As with the European analysis, Transport is again the best performing infrastructure asset, with an annual return of 8.90% and an annual volatility of 23.43%, resulting in a Sharpe Ratio of 0.320. The worst performing infrastructure asset is Energy, with an annual return of 3.30% and an annual volatility of 19.61%, resulting in a Sharpe Ratio of 0.096. In comparison with more traditional assets, all of the infrastructure listed sectors perform better than Real Estate. Transport and Telecom also perform better than Stocks. However, similar to the European analysis, Government Bonds performs best, with an annual return of 4.76% and an annual volatility of 8.65%, resulting in a Sharpe Index of 0.388, highest of all the assets.

Table 7.2: UK Infrastructure Sector Performance Analysis during the Financial Crisis Q4.2007-Q2.2009

UK listed asset	Annualised Return	Annualised Volatility	Sharpe Index	Rank
Energy	-5.31%	26.09%	- 0.23	1
Telecom	-24.68%	22.94%	-1.10	4
Utilities	-25.80%	34.53%	-0.77	3
Transport	-49.79%	38.25%	-1.32	6
Stock	-22.91%	21.05%	-1.12	5
Real Estate	-65.63%	34.28%	-1.93	7
Government Bond	-2.58%	11.63%	- 0.28	2

United Kingdom sector performance during the financial crisis

Following the European sector analysis, we contract the dataset for the United Kingdom to the crisis period (Q4. 2007-Q2. 2009); this allows us to isolate the effect of the financial crisis and compare the robustness of listed infrastructure sectors in a recession at national level.

As we can see from Table 7.2, Energy performs better than any other asset during the financial crisis. However, all infrastructure sectors are less negatively affected than Real Estate; and with the exception of Transport, the other infrastructure sectors also perform better than Stocks. The least affected asset during the recession is Energy, perhaps due to the necessity for Energy in our everyday lives.

Diversification Benefits among assets

The results of the cross-asset correlation are presented in Table 7.3. As we can see from the table, infrastructure sectors are moderately correlated with each other, which means that little diversification benefit will be achieved from constructing a portfolio that invests in only infrastructure sectors.

Furthermore, all infrastructure sectors show high correlation with Stocks. This is expected, as the indices used are from publicly-traded infrastructure companies. It is noteworthy that all of the infrastructure sectors show low correlation with

Table 7.3: Cross Asset Correlation Matrix for UK Monthly Returns Q1.2003-Q4.2013

Assets	Energy	Utilities	Telecoms	Transport	Stocks	Real Estate	Government Bonds
Energy	1						
Utility	0.532	1					
Telecom	0.416	0.449	1				
Transport	0.371	0.546	0.431	1			
Stocks	0.727	0.706	0.576	0.708	1		
RealEstate	0.289	0.547	0.298	0.630	0.665	1	
Government Bonds	0.042	0.461	0.022	0.159	0.123	0.205	1

government bonds, indicating that the construction of a portfolio investing in infrastructure and government bonds will result in diversification benefits.

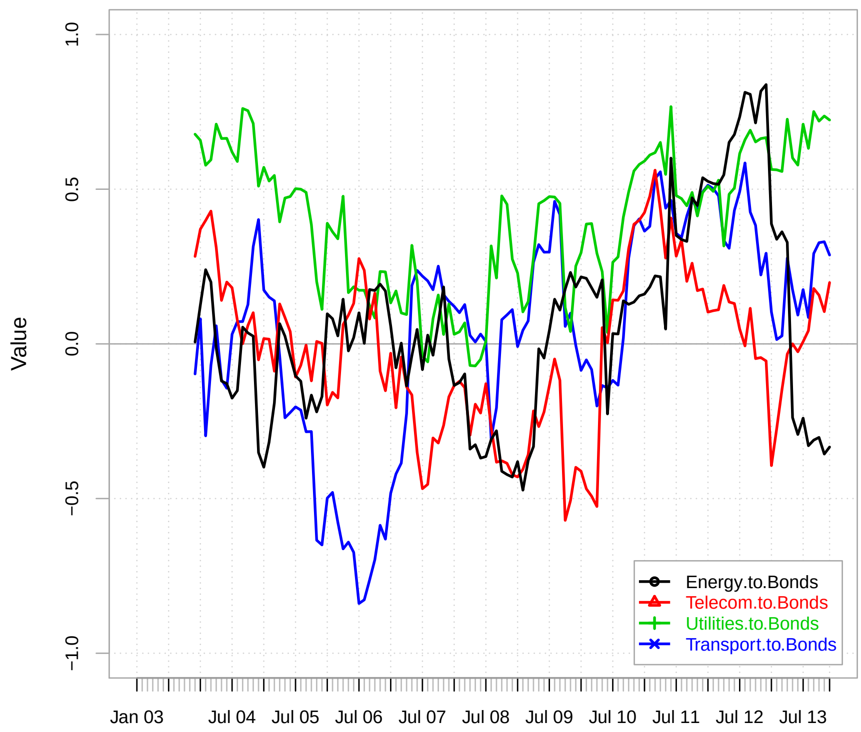


Figure 7.1: Rolling Correlation of UK infra sectors with Government Bonds

Rolling correlations among traditional assets have been plotted to examine the correlation of each infrastructure sector with traditional assets over the years. In Figure 7.1 the rolling correlation between infrastructure sectors and government

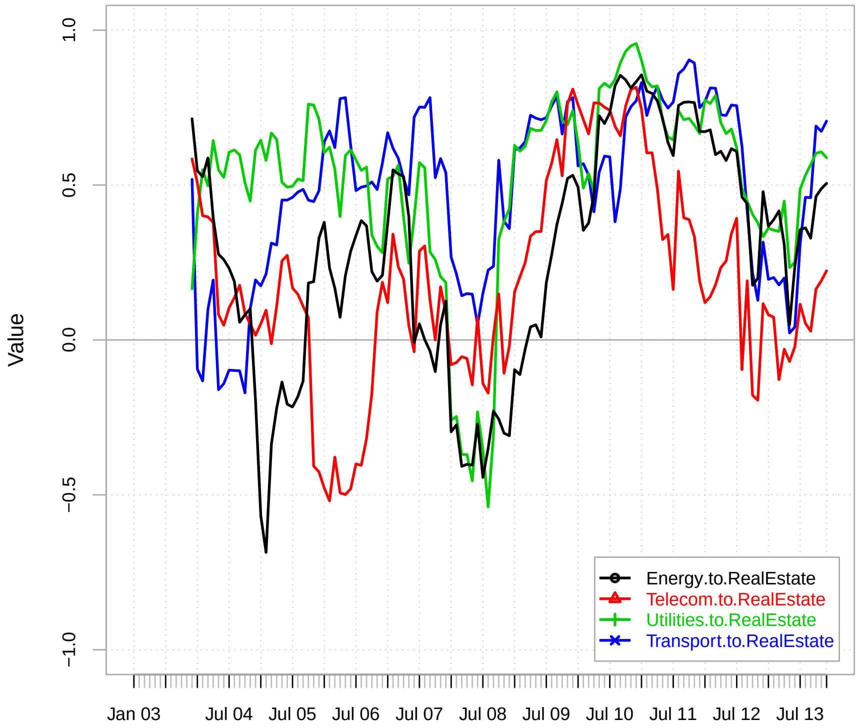


FIGURE 7.2: Rolling Correlation of UK infra sectors with Real Estate

bonds is depicted in Figure 7.1, indicating many differences throughout the period examined.

When we turn to the correlations of infrastructure sectors with real estate in Figure 7.2 we detect differences between infrastructure sectors, particularly in the first half of the dataset and towards the end of the dataset in 2011. One striking difference is shown in the energy sector, where the correlation of energy with real estate decreases substantially in the early months of 2004, while simultaneously in all other infrastructure sectors' correlation with real estate increases. A similar observation can be seen for telecoms; the correlation between telecoms and real estate decreases in 2005, while simultaneously in all the other infrastructure sectors, correlation with real estate increases. The same differences are noted in Figure 7.3 where the rolling correlations between all the infrastructure sectors with stocks are drawn. Once again, we can conclude from our results of the rolling correlation

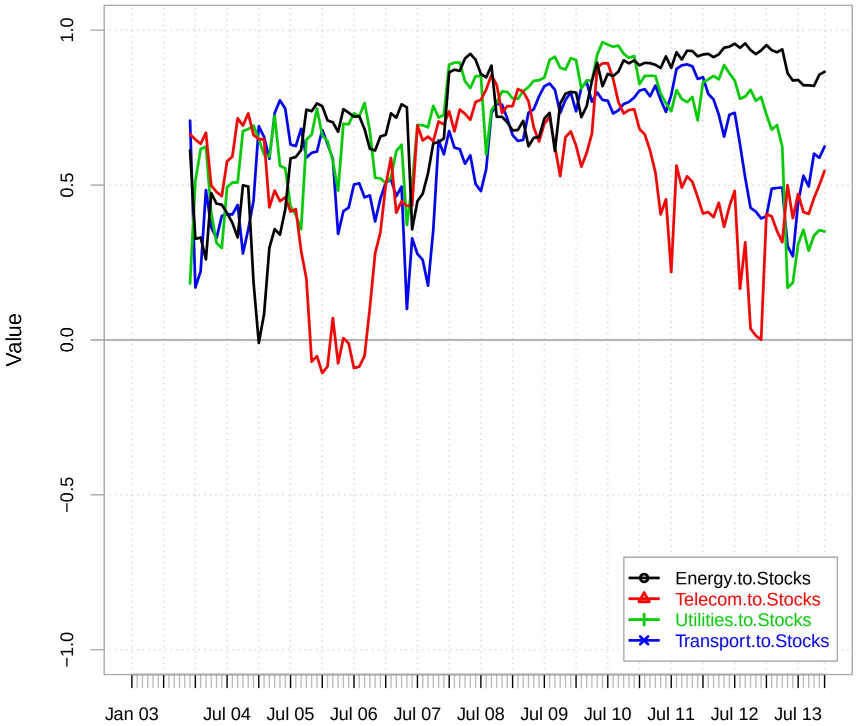


FIGURE 7.3: Rolling Correlation of UK infra sectors with Stocks

examination that differentiation exists among infrastructure sectors and point to the necessity for close attention to, and deeper understanding of, the individual infrastructure sector.

Lastly, in Figure 7.4 and Figure 7.5, we present the rolling correlations among all infrastructure sectors to examine the extent to which infrastructure sectors move together. The correlations are not consistently high, particularly for the years before the financial crisis and recent years, proving that not all infrastructure sectors move together.

Robustness analysis

To check the above conclusions and thus to avoid bias, a second index of each traditional asset has been selected as a control.

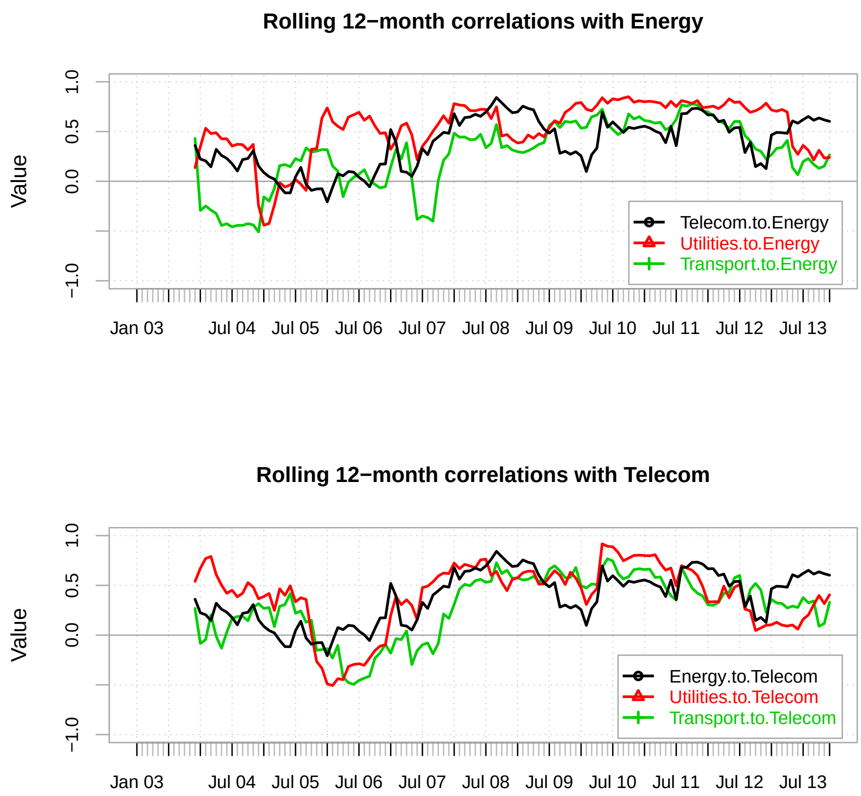


Figure 7.4: Rolling Correlation of UK infra sectors with Energy and Telecom

We have been able to confirm our conclusions in the robustness analysis. All the assets have the same rank, with Government Bonds as the best performing asset and Real Estate with the worst performance. Similar to our analysis above, Stocks perform better than Energy and Utilities, but are outperformed by Transport and Telecoms.

In the robustness analysis we re-calculate the cross-asset correlation matrix using the control indices. We can confirm that infrastructure assets show high correlation with Stocks and Real Estate but low correlation with Government Bonds. In fact, in the robustness analysis the Energy sector is negatively correlated with Government Bonds. We can therefore confirm on the basis of our robustness analysis that constructing a portfolio investing in Government Bonds and infrastructure sectors will offer diversification benefits.

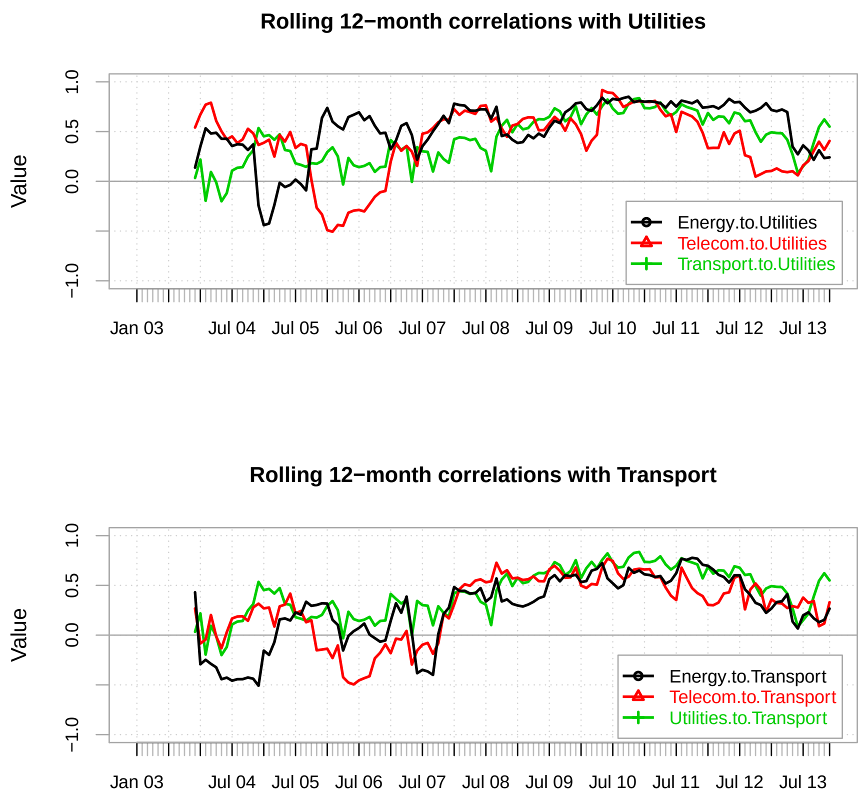


FIGURE 7.5: Rolling Correlation of UK infra sectors with Utilities and Transport

7.4 Results Objective 2: United Kingdom Portfolio analyses with and without infrastructure

Investors have ranked the UK as one of the best countries for investment in Europe, and the second-best country for infrastructure investments compared to the United States (Oyedele, 2014). Given the increased demand for UK infrastructure assets we think it would be interesting to examine the significance of different UK infrastructure sectors within the traditional portfolio. In order to tackle this objective we analyse two types of portfolio:

- Portfolio 1 includes only United Kingdom traditional assets (Stocks, Real Estate and Government Bonds).
- Portfolio 2 includes the same assets as Portfolio 1 plus UK infrastructure sectors (Energy, Telecoms, Utilities and Transport).

By creating a portfolio comprising only of traditional assets, it is possible to achieve a higher Sharpe ratio than if we were to invest in just one traditional asset, proof positive that a portfolio of traditional assets offers diversification benefits. The maximum Sharpe Ratio is obtained by investing 33.16% in Stocks and 66.84% in Government Bonds, resulting in a Sharpe ratio of 0.471. However, if we invest only in Government Bonds, this choice yields a lower Sharpe ratio of 0.388.

On the other hand, when we add infrastructure to the portfolio, performance improves. Figure 7.6 shows the efficient frontier of UK portfolio with and without infrastructure. Similar to the European analysis, adding infrastructure in a traditional portfolio shifts the efficient frontier to the right, offering greater returns for holding the same amount of risk.

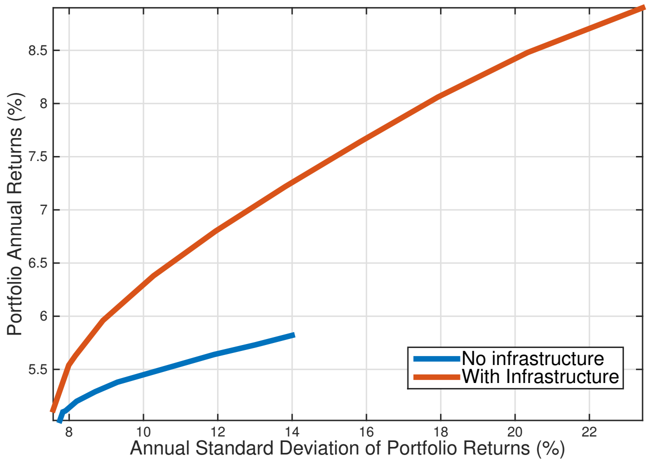


FIGURE 7.6: Efficient Frontiers for Portfolios 1 and 2

The portfolio that maximises the Sharpe Ratio invests 6.6% in Transportation, 19.7% in Telecoms, and 66% in Government Bonds, resulting in a Sharpe ratio of 0.516. The portfolio combination among infrastructure and government bonds is illustrated in Oyedele (2014) however, in Oyedele's paper the analysis is not broken down into different sectors. In order to examine different portfolio configurations for different levels of risk and returns, the reader is referred to Appendix C.

7.4.1 Robustness analysis

In this section we test the robustness of our mean-variance optimisation by performing a M-CVaR optimisation. We first compare the two efficient frontiers in a mean-variance plot, as shown in Figure 7.7. We see that the two efficient frontiers are similar at the two ends: for low and high levels of returns, the two optimisations offer similar results, however, for medium returns the two optimisations differ.

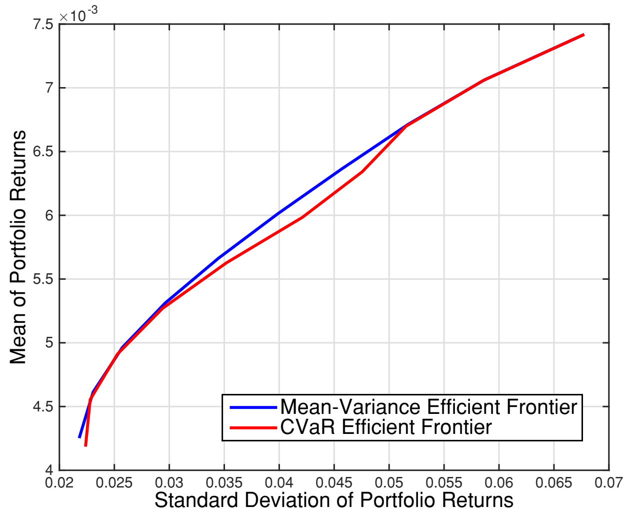


FIGURE 7.7: Efficient Frontier comparison for portfolios mean-variance and M-CVaR optimisation of Portfolio 2

Thereafter, when we use area plots to visualise differences in the allocation of assets in Figure 7.8 we can deduce that the mean-variance optimisation allocates generally more weight to Transport and less to Telecoms. Furthermore, the M-CVaR weights allocate a very small weight to real estate as well, where real estate is not included in any of the efficient frontiers of the mean-variance optimisation. However, in both optimisations we can conclude that mainly the portfolio invests in Transport, Telecoms and Government Bonds.

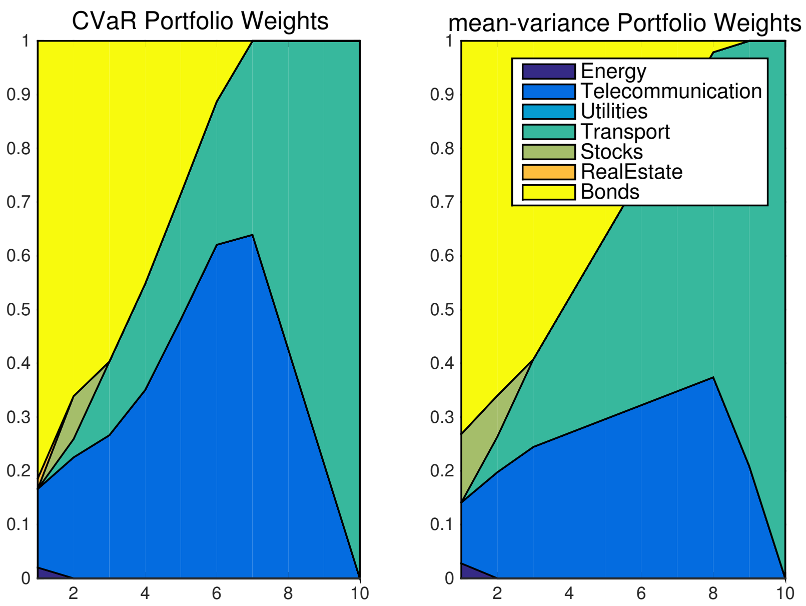


FIGURE 7.8: Weights comparison for portfolios mean-variance and M-CVaR optimisation of Portfolio 2

Based on our analyses here, infrastructure is a good addition to a portfolio. And contrary to the European analysis, we find that in the United Kingdom, infrastructure sectors can mix in the construction of the optimal portfolio.

7.5 Conclusions

Infrastructure investment in the United Kingdom has contributed significantly to the development of its economy. This chapter has addressed some of the same research questions handled in the European analysis in Chapter 5, but now applied to the United Kingdom listed infrastructure market. Despite the fact that the UK market is one of the most established and attractive infrastructure markets in the world, little research has appeared on this front (Oyedele, 2014).

We have captured the differences in the performance of different economic infrastructure sectors, e.g., Energy, Utilities, Telecoms, and Transport over a period that also takes the financial crisis period into account. We aimed to identity the most beneficial infrastructure sectors in which to invest when creating a portfolio.

The findings of the UK analysis indicate that, similar with the European analysis, infrastructure sectors differ in their performance histories, so asset managers will need to focus particular attention on a specific sector, i.e. our country analysis also confirms the results of the European regional analysis: infrastructure sectors not only differ at regional level but they also differ at country level.

The results of part two of the analysis indicated that investing in infrastructure can create higher returns for the same level of risk. Unlike the European context, infrastructure sectors do mix when constructing a portfolio of infrastructure sectors and traditional assets. The research conducted here supports the aims of the UK government which seeks to increase private sector participation in UK infrastructure investment. It is important, however, for investors to keep in mind that infrastructure is not a risk-free asset; nevertheless, our results indicate that if a private investor fully understands specific infrastructure sectors, it will be possible to invest in certain infrastructure sectors and gain more attractive returns while bearing the same amount of risk.

After having analysed the listed infrastructure market, we now turn to a comparison of the listed with the unlisted infrastructure market in order for investors to better understand the differences between them. The next chapter will address this topic by comparing two ways of investing and by offering insights into the best ways to access the infrastructure market. Through this next study we focus on how to increase participation among institutional investors in the infrastructure market.

Chapter 8

Portfolio of Infrastructure Investments: A Comparison between a Listed and an Unlisted Infrastructure Portfolio

8.1 Introduction

Worldwide, infrastructure investments have risen to the top of many government strategic priority lists as a fundamental way to build economies (Balesh, 2012). Investments in infrastructure projects stimulate growth, both through the creation of jobs and by increasing the competitiveness of countries (Schwartz, 2011). According to Robert and Herbert (2014), the infrastructure requirements needed to sustain economic growth globally until 2030 exceed US $57 trillion, bringing to light the scale and urgency of these investments as leverage for economic growth. However, different austerity measures in place since the financial crisis of 2008 have hindered governments in their aim to invest in infrastructure to the levels of previous years.

As a result of public budget constraints, the widening infrastructure gap is expected to be bridged by private investors. Although institutional capital is available, and despite the fact that private investors are increasingly looking for opportunities to invest in the infrastructure market, the gap remains wide (Richard et al., 2013). Practitioners attribute lagging investment to issues in the infrastructure market that undermine infrastructure deals for investors. As Jim Barry, head of infrastructure at BlackRock argues, 'there is absolutely zero correlation between the scale of need for infrastructure and addressable opportunities' (Authers, 2015).For instance, investors are keenly aware of the two main critical issues, political/regulatory risk and structural weakness, which are associated with infrastructure investment (Bitsch et al., 2010). In regard to reduction of political and regulatory risk, governments are responsible for presenting credible infrastructure strategies; however, until now governments have publicised only a list of projects in order to convince private investors that the projects will take place (Panayiotou and Medda, 2014*a*). For instance, in the Juncker plan, while many projects have been approved only four-fifths have been signed (Financial Times, 2017).

In this chapter, rather than to focus on regulatory risk, close attention is given to the structural problems inherent in infrastructure. To do so, we examine the three main ways for investors to access the market. Investors can enter in two ways via the Unlisted infrastructure market, using either direct investments into infrastructure projects or indirect investments into investment vehicles known as Unlisted infrastructure funds. The third access vehicle into infrastructure is through the Listed infrastructure market, which includes publicly traded securities issued by companies that own and/or operate infrastructure assets (Adam, 2014).

The opportunities and risks presented by the Unlisted infrastructure market are fairly easy to describe. Direct investments in infrastructure provide investors with the benefit of full transparency of the asset in addition to more operational control (Inderst, 2009). Operational control lies more with industrial investors such as the PPP consortia that bid for large infrastructure projects. On the other hand, financial investors that only invest equity in an infrastructure asset do not have any operational control nor bear any operational risks. However, direct investments are highly illiquid, they include large amounts of leverage, and unless the required expertise is in place, the investor will also be exposed to significant operational risks (Della Croce, 2011, Della Croce et al., 2011). Furthermore, direct investments require large outlays of capital that essentially wipe out any diversification benefits (CBRE, 2014, Chhambria et al., 2015).

On the other hand, indirect investments offer greater diversification benefits because Unlisted infrastructure funds invest in several infrastructure projects across different geographies and sectors. Another advantage of indirect investments is that they allow less capital requirements (Inderst, 2009). Despite their advantages, the indirect option is still very illiquid. Unlisted infrastructure funds have a similar structure to private equity funds, which are usually close-ended funds with large holding periods of 10-15 years (Panayiotou and Medda, 2014*a*). Different from the real estate market, where a number of open-ended vehicles offer investors an exit option, the Unlisted infrastructure market does not yet have as many open-ended funds. In this case, investors do not have the possibility of liquidating their positions. For instance, as highlighted by Infra Deals Database, their funds database includes 289 Unlisted infrastructure funds, 273 of which are close-ended and only 16 are open-ended (Infra Deals, 2016*b*). Further drawbacks of the Unlisted infrastructure market include lack of transparency within the funds, which makes the calculation of returns and risks extremely challenging (CBRE, 2014, Della Croce et al., 2011), the structure of Unlisted funds does not satisfy investor appetite, and lastly, substantial fees paid to fund managers is the norm (Panayiotou and Medda, 2014*b*).

When pension funds first entered the market, indirect investment was the main route of access to infrastructure (Inderst, 2009). Della Croce (2011) noted in 2011 that less than 1% of pension funds were invested directly in infrastructure projects. Direct investments were only carried out by various larger Canadian and Dutch pension funds, which, as pioneers in the infrastructure market in the 1990s, were the first to gain the expertise, knowledge and resources for investing directly through co-investing (Della Croce, 2011). However, the problems posed by the indirect infrastructure vehicles has made them less popular. Nowadays pension funds are likely to bypass infrastructure funds altogether and invest directly in infrastructure (Della Croce et al., 2011); not only is this the case for the most experienced investors, i.e. Canadian funds, but European pension funds are also seeking greater operational control and higher rewards in this asset class (Dunning, 2015). For instance, the Lancashire County Pension Fund (LCPF) is one of the standout European pension funds willing to gain more direct exposure to the infrastructure markets. However, to date, only a few pension funds are able to invest directly in infrastructure. Direct investment is not an option for every investor, and this holds particularly true for small and medium-sized pension funds (Della Croce, 2011, Della Croce et al., 2011, Dunning, 2015).

As an alternative, a number of scholars have suggested that the Listed infrastructure market presents good opportunities for small and medium-sized pension funds as well as private investors not convinced by the Unlisted infrastructure market (Della Croce, 2011). A second school of thought also supports the idea that investments in Listed infrastructure provide the best access to infrastructure (Adam, 2014, CBRE, 2014, Reyes, 2014). Listed infrastructure consists of publicly traded infrastructure companies that have been operating infrastructure assets much longer than institutional investors. During the 1990s, a series of privatisations of infrastructure assets (valued at approx. US $600 billion) took place in OECD countries, leading to the proliferation of publicly traded infrastructure companies in the market that, until now, had been directly operating and managing infrastructure assets (Chhambria et al., 2015). Thus, as Chhambria et al. (2015) assert, the knowledge and expertise gained by infrastructure companies over the years makes them more appropriate owners of infrastructure assets than institutional investors; and despite investing directly, these companies can still benefit from diversification, as they already have infrastructure portfolios and sufficient capital to invest in still more infrastructure assets. A further advantage is that they are transparent and credible enough to gain the trust of the capital markets, thereby gaining access to attractive financing. It should be pointed out here that similar with unlisted investments and as described in 1, buying stocks in a company means participating to the ownership of a company and it is different to buying shares on a listed infrastructure fund where the corporate governance implications lie with the limited partners of the fund.

All the aforementioned, in combination with the monopolistic characteristics of infrastructure assets, offer numerous advantages to private investors seeking to invest in Listed infrastructure. Firstly, the listed market provides a highly liquid option to an otherwise illiquid asset class (Adam, 2014), allowing for lower liquidity risk and frequent rebalancing of the portfolio. Secondly, even though Listed infrastructure is a subset of the equity market, scholars argue that it is more robust and gives greater downward protection than the rest of the equity market (Adam, 2013). Interestingly, an investment in Listed infrastructure requires no operational expertise, invested capital can range from absolute minimum to high, and high levels of transparency would be the norm (CBRE, 2014).

Higher transparency would allow investors to focus. As demonstrated in Panayiotou and Medda (2016), infrastructure sectors and sub-sectors offer different investment characteristics. The ability to focus helps investors to concentrate on a single sector, or to select which infrastructure sectors or sub-sectors they prefer to allocate equity. Additionally, although Listed infrastructure datasets are smaller compared to traditional markets, we can safely say that in relation to the Unlisted infrastructure market, in Listed infrastructure sufficient historical data is available for us to analyse the returns, risks and correlations.

However, there still remains insufficient empirical evidence on the returns of infrastructure investments to boost private investor confidence towards infrastructure assets. Despite the rising popularity of infrastructure, scant datasets on infrastructure investments still hinders much of the academic research (Dechant et al., 2010, Newell et al., 2011, Peng and Newell, 2007). As a result, large amounts of capital remain un-invested at a time when these investments are needed the most (Robert and Herbert, 2014).

In this study we aim to shed light on the theretofore-elusive access to Unlisted infrastructure fund performance. To our knowledge, the only studies using Unlisted infrastructure fund data are Bird et al. (2014), Newell et al. (2011), Peng and Newell (2007), but their data refers to Australia and their studies neglect to carry out optimisation analyses. Moreover, the bulk of the studies using Listed infrastructure data treat infrastructure in their portfolios as a single sector and do not consider different infrastructure sectors and sub-sectors. As Panayiotou and Medda (2016) have shown, each infrastructure sector and sub-sector has its own performance profile, thus raising different implications for the construction of infrastructure portfolios.

The objective of this chapter is to contribute to the literature by studying in detail the performance of a portfolio investing in Listed infrastructure sectors and traditional assets, and one investing in Unlisted infrastructure and traditional assets. The two methods of allocating in infrastructure (Listed and Unlisted) within a traditional portfolio are fully exploited. Thus, the task of this chapter is to observe whether the liquidity, transparency and rebalancing option provided by the Listed infrastructure sectors offers better portfolio performance than investing a fixed allocation into the Unlisted infrastructure market with no possibility of exit. When the Unlisted infrastructure is analysed, we apply a unique Unlisted infrastructure index developed by Preqin that captures the performance of 200 Unlisted infrastructure funds from (Q1.2008 - Q2.2015). The data on Listed infrastructure consists of a historical time series of monthly returns of different European infrastructure sector indices (Energy, Utilities, Telecom, and Transport) over a 13-year time span (2003-2015). By calculating the best technique and strategy in the optimisation of infrastructure, the author hopes to raise investor confidence and, in turn, increase private sector participation in infrastructure.

8.2 Data and research methodology

The data used is collected from Thomson Reuters Database and Preqin online infrastructure database. Listed infrastructure data consist of a historical time series of quarterly returns of different Thomson Reuters European Listed infrastructure sector indices (Energy, Utilities, Telecom, and Transport) over a 13-year time span

(2003-2015), along with traditional assets represented by indices of Stocks, Real Estate and Government Bonds. In order to capture the Unlisted infrastructure market, the Preqin index enables us to identify the performance of 200 Unlisted infrastructure funds that have raised an aggregate capital of more than US$230bn. The index shows the performance of these funds over a 7-year period, from Q1.2008 to Q2.2015. Preqin developed this index from its online infrastructure data using quarterly Net Asset Values (NAV) and cash flow transactions. The index is Gross of fees and the transaction costs of rebalancing the portfolio are not taken into consideration.

To carry out the task of this chapter, we perform an out-of-sample analysis, where part of the data is used for scenario generation and the remainder is used to evaluate the results of the optimisations, as in Chapter 6. To employ the out-of-sample analysis, the first two years of the data, Q1.2003 to Q4.2004, are used as the in-sample data for constructing the first portfolio to build into. The prices in the next quarter (Q1.2005) are then used to calculate the portfolio's value. This quarter is thereafter added to the in-sample data for scenario generation to decide the allocation of investments for Q2.2005, and so on. The adding-in process is continued for the whole dataset in order to evaluate the portfolio performance of each strategy.

The portfolio investing in traditional assets and Listed infrastructure is highly liquid; for this reason, the portfolio is rebalanced every quarter to evaluate the efficient infrastructure sector allocation over time. In the portfolio investing in Unlisted infrastructure, the infrastructure allocation remains fixed at 10% across the 7 years in order to adhere to the required holding period for infrastructure funds. The portfolio is re-balanced every quarter among the traditional assets, keeping only the 10% infrastructure allocation fixed, which is the usual amount that pension funds designate to infrastructure investments.

Thereafter we examine the performance of the optimal portfolios based on the annual returns, annual volatility and Sharpe Ratios. The Sharpe Ratio is calculated using Treasury Bills as a risk-free asset. In the MVO, the optimal portfolio is determined as the portfolio that maximises the Sharpe Ratio. The description of the MVO analysis is presented and described in detail in Chapter 3.

8.3 Results

8.3.1 Descriptive statistics and diversification benefits

This section will first go over the summary statistics for each asset and then present and discuss the results of the portfolio optimisations. Table 8.1 gives the summary statistics for each asset, in which annual returns, annual volatility and Sharpe Ratios have been calculated. We can see from Table 8.1 that Listed infrastructure sectors behave quite differently between each other, and transport is the best performing sector of the infrastructure assets. Conversely, energy is the worst performing infrastructure sector, as shown by a negative Sharpe Ratio. The poor performance of the energy sector can be explained by plummeting oil prices which have also impacted negatively on the shares of Listed energy companies. All infrastructure sectors (apart from energy) perform better than the rest of the equity market (stocks), while all infrastructure sectors are seen to be less volatile than real estate. Unlisted infrastructure shows a strong performance with high annual returns and low volatility. This holds especially true if we take into account that the Unlisted infrastructure data is shorter, and a large part of the data includes the years of the financial crisis.

When the correlation benefits between Listed infrastructure sectors and other assets are examined in Table 8.2, we notice that, apart from showing a negative correlation with government bonds, Listed infrastructure sectors are highly correlated - not only with other asset classes - but also between each other. Thus, apart from the strong diversification benefits with government bonds, we find no other significant diversification benefits in the Listed infrastructure sectors.

The results are distinctly different however, when diversification benefits within the Unlisted infrastructure market are examined. The diversification benefits among

Table 8.1: Historical Performance Analysis of all Assets

Asset	Annual Return	Annual Volatility	Sharpe Ratio
Period Q1.2003-Q4.2015			
Energy	0.25%	24.10%	-0.05
Telecom	3.41%	20.20%	0.11
Utilities	3.67%	21.75%	0.11
Transport	7.74%	24.29%	0.27
Stocks	3.02%	19.99%	0.09
Real Estate	5.94%	27.91%	0.17
Government Bonds	4.57%	4.65%	0.71
Period Q1.2008-Q2.2015			
Unlisted Infrastructure	7.39%	9.10%	0.78

Table 8.2: Cross Asset Correlation Matrix for Quarterly Returns Q1.2003 to Q4.2015

	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Government Bonds
Energy	1						
Telecom	0.759	1					
Utilities	0.820	0.850	1				
Transport	0.734	0.789	0.852	1			
Stocks	0.721	0.658	0.703	0.658	1		
Real Estate	0.583	0.648	0.758	0.824	0.738	1	
Government Bonds	-0.524	-0.315	-0.433	-0.330	-0.427	-0.302	1

Table 8.3: Cross Asset Correlation Matrix for Quarterly Returns Q1.2008 to Q2.2015

	Unlisted Infra	Energy	Telecom	Utilities	Transport	Stocks	Real Estate	Government Bonds
Unlisted Infra	1							
Energy	-0.083	1						
Telecom	-0.010	0.775	1					
Utilities	0.106	0.857	0.865	1				
Transport	-0.110	0.774	0.865	0.900	1			
Stocks	-0.064	0.756	0.743	0.752	0.779	1		
Real Estate	0.030	0.645	0.711	0.812	0.887	0.816	1	
Government Bonds	-0.005	-0.584	-0.409	-0.520	-0.420	-0.487	-0.395	1

all assets for the period between Q1.2008 to Q2.2015 are reassessed in order to also account for the Unlisted infrastructure assets. In Table 8.3, Unlisted infrastructure is not correlated with the rest of the assets, and we can see that Unlisted infrastructure shows a negative correlation with all assets, except real estate and Listed utilities, where the correlation may not be negative, but it is nevertheless very low.

Thus, one can argue that Unlisted infrastructure presents substantial diversification benefits with all traditional assets as well as with Listed infrastructure. Low and negative correlation between Listed and Unlisted infrastructure has also been demonstrated in Newell et al. (2011), Peng and Newell (2007), RREEF (2015).

8.3.2 Comparison of a Portfolio investing in Listed and Unlisted infrastructure using the MVO approach

In this section our chapter objective is addressed by comparing a portfolio that invests in Listed infrastructure with a portfolio investing in Unlisted infrastructure using mean-variance optimisation (MVO). We construct one liquid portfolio which invests in Listed infrastructure sectors along with stocks, real estate and government bonds from Q1.2003 to Q4.2015, where the portfolio is re-balanced every quarter through 2015. However, our Unlisted infrastructure portfolio invests only in traditional assets for the first 3 years of the portfolio, and from Q1.2008 to Q2.2015 a fixed allocation of 10% is invested in Unlisted infrastructure. Except for Unlisted infrastructure, which remains fixed at 10%, the rest of the portfolio is re-balanced every quarter across the whole period, similar to the portfolio that invests in Listed infrastructure.

The portfolio with Unlisted infrastructure shows the best overall performance, with an annual return of 4.34% and volatility of 4.82%, resulting in a Sharpe Ratio of 0.635; while the portfolio that invests in Listed infrastructure has a Sharpe Ratio of 0.406, with an annual return of 3.36% and volatility of 5.12%. Figure 8.1 gives the quarterly returns for both portfolios. As we can see, although the performance of the Listed portfolio initially shows superior performance, with the introduction of Unlisted infrastructure into the portfolio in 2008 the performance of the Unlisted portfolio shows a better overall performance in the following years.

Since the traditional assets of the two portfolios are the same, the author is confident that the differences in the two portfolios arise from allocating into Unlisted infrastructure instead of Listed infrastructure. Figure 8.2 and Figure 8.3 depict

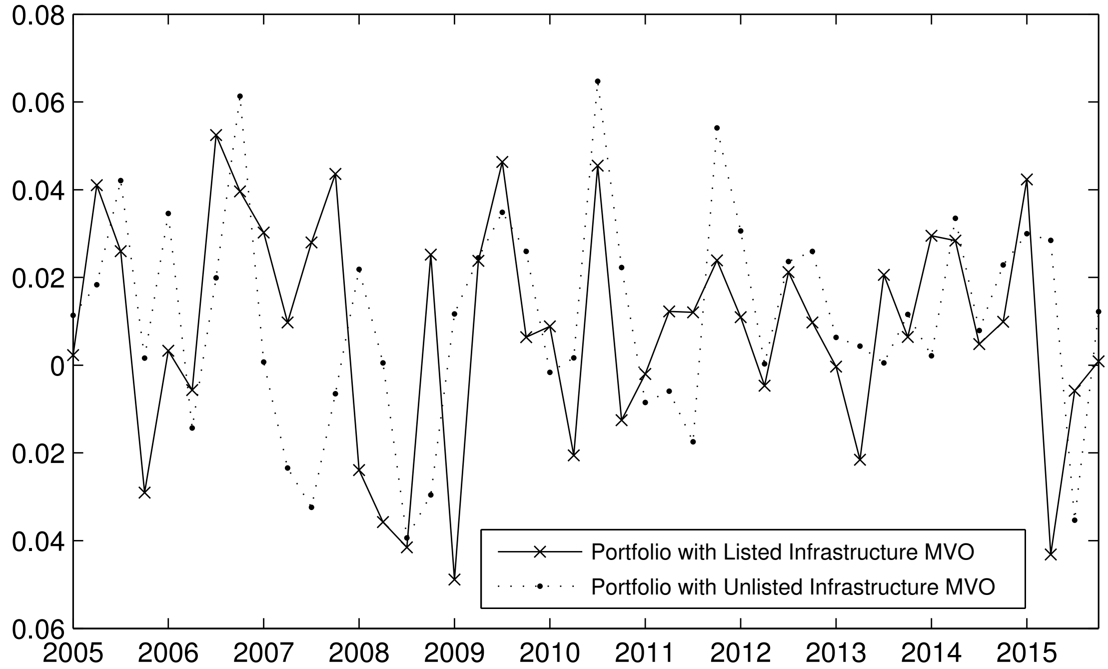


Figure 8.1: Historical Quarterly Returns of Listed and Unlisted Infrastructure portfolios

area plots of the allocation of assets over time. Both portfolios are concentrated mainly in government bonds. Figure 8.2 portrays how, by using a standard MVO, the portfolio that maximises the Sharpe Ratio over time invests mainly in government bonds and in Listed infrastructure, with very few allocations in stocks and real estate. It is therefore beneficial for investors to reallocate their stock allocations into specific Listed infrastructure sectors. Moreover, it is worth mentioning that during a period of financial crisis it is optimal for investors to reallocate their traditional asset weights and invest more in transport and utilities. Our findings indicate that some infrastructure sectors are less volatile than stocks or real estate and could provide more protection during a period of crisis.

When Listed infrastructure is no longer an option, we can notice that apart from the fixed allocation into Unlisted infrastructure, the portfolio allocates into real estate and government bonds.

Our results confirm that, despite not being able to liquidate or reallocate investor weights, investing in Unlisted infrastructure within the institutional portfolio is

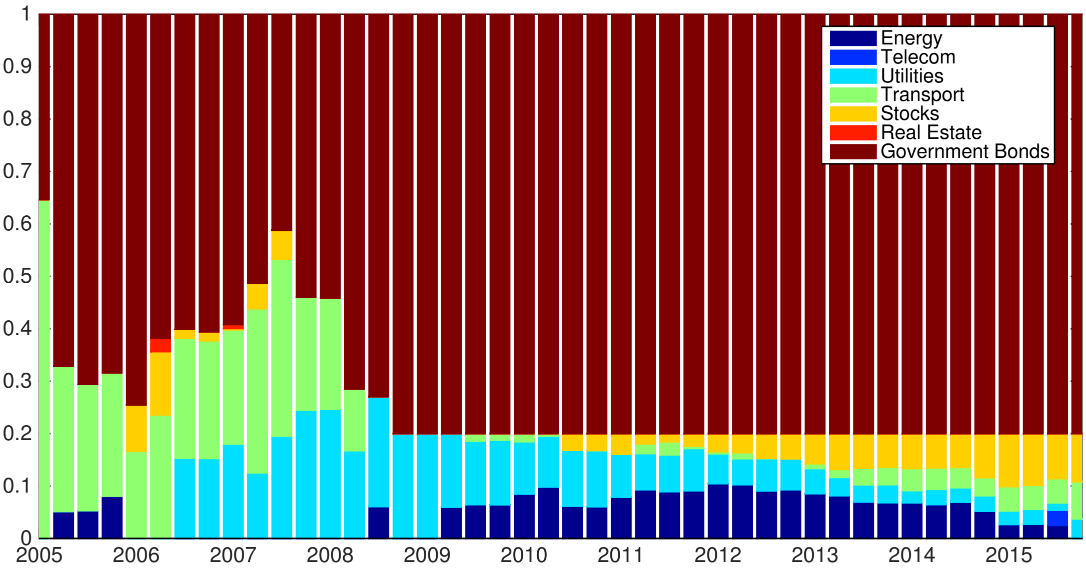


FIGURE 8.2: Transition map for Listed Infrastructure portfolio

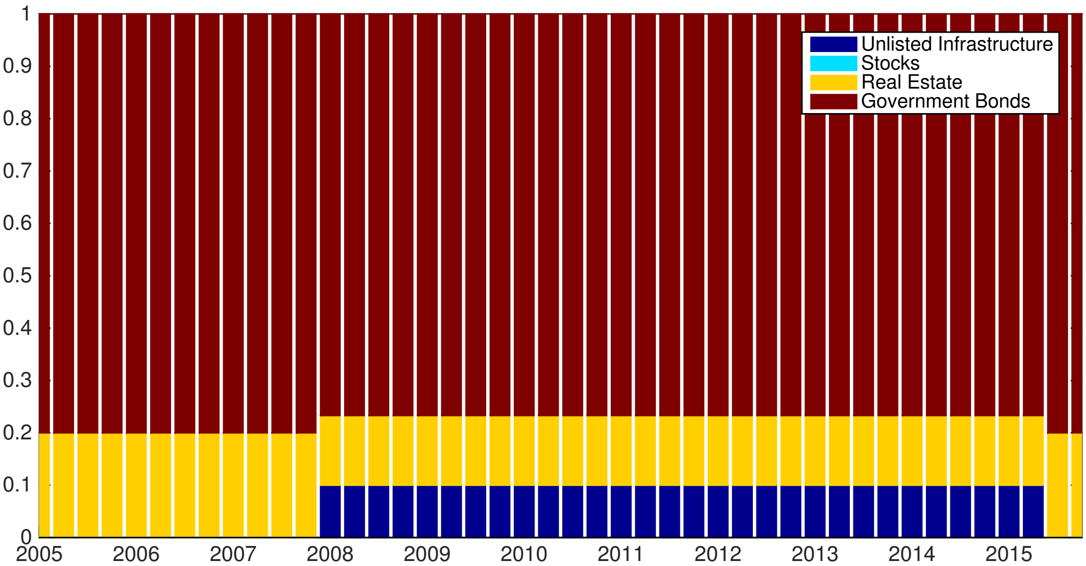


FIGURE 8.3: Transition map for Unlisted Infrastructure portfolio

more efficient than investing in Listed infrastructure. For this reason, the author strongly believes it is to the advantage of investors, fund managers and the overall economy of the country to solve issues pertaining to indirect infrastructure investments. In other words, by tailoring investment vehicles to be more suitable for the investors, they will be encouraged to invest and will increase the participation of pension funds in the Unlisted indirect infrastructure market. Another way to boost participation is to increase investor confidence in regard to infrastructure investments. Providing greater transparency in the Unlisted infrastructure fund market, as we have achieved in this study, is one way forward. The MVO results demonstrate that Listed infrastructure is still a favourable way to improve portfolio performance, given that some sectors perform better than others and have more built-in defensive characteristics than the rest of the equity market. Listed infrastructure could be a good option for small, medium-sized institutional investors and some retail investors.

8.4 Conclusions

Investment opportunities in infrastructure are likely to reach funding requirements of trillions of dollars by 2030 (Robert and Herbert, 2014). Thus, in order to begin closing the infrastructure gap, investors should continue to be urged to invest in this asset class. However, in the face of structural weaknesses in the infrastructure vehicles, limited empirical evidence on the robustness of these investments, and lack of transparency, investors are still deterred from, and suspicious of, investing largely in infrastructure. In our aim to instil investor confidence in this under-utilised asset class, we have addressed these perception issues by carrying out analyses of the infrastructure market and in so doing, have uncovered its attractive risk/return profile.

To provide greater transparency to the highly opaque Unlisted infrastructure fund performance, we have confirmed that investing in Unlisted infrastructure, despite its rebalancing and illiquidity risks, can still offer more advantages than investing in Listed infrastructure within a traditional portfolio. It is strongly believed that pension funds should continue to allocate through indirect investments, particularly those funds lacking the required expertise to manage the types of risk associated with direct infrastructure investments. It is true that infrastructure markets never stay still Dunning (2015), and as the market matures more investors are expected to exhibit risky profiles, preferring to invest directly in infrastructure. However, this transformation is expected to occur gradually as investors gain knowledge and experience of the asset class, and as the sector matures. Currently, the majority of pension funds are not in the position to invest directly.

The most pressing priority, in this author's view, is to resolve all the issues posed by the indirect Unlisted infrastructure market which will likely unlock more institutional capital for infrastructure. Unlisted infrastructure funds are known for their unwillingness to disclose information in regard to their strategy and performance. Making this market more transparent will, as argued here, attract further flows of capital from institutional investors. Moreover, having a well-recognised infrastructure benchmark in place could enable investors to gain confidence in this asset class, as they will better understand, compare and manage the risks they encounter. The illiquidity of these funds could also be addressed if more open-ended funds were to be developed in the market. Other structuring issues with these investments, such as the high fees required by fund managers, should also be resolved as soon as possible. If these issues are not corrected by the market, then this presents an example of market failure which calls for government intervention.

Nevertheless, even if all of the problems confronted in the Unlisted market were either resolved or ignored and investors were willing to commit more capital into infrastructure assets through the Unlisted market, the infrastructure gap would not yet be filled. There is room in the market for a different kind of capital, one that can attract increasing numbers of small to medium-sized pension funds and retail investors. In this study, we have shown that certain Listed infrastructure sectors e.g., transport and utilities, outperform the equity market. Listed infrastructure can offer a defensive side to the portfolio when the market drops, thereby giving more tail risk protection. In effect, by investing in public infrastructure companies Listed on global exchanges, investors have opportunities to access to infrastructure without committing to long-term illiquid investment.

By targeting the weaknesses of Unlisted infrastructure and learning more about infrastructure assets, both private investors and governments will benefit from this asset class, respectively, through better protection and performance and by arriving ever closer to the infrastructure goals of governments.

Chapter 9

Conclusion

In Chapter 1 we witnessed that the infrastructure requirements needed to sustain economic growth in both the developed and the developing world are in the trillions of dollars (Richard et al., 2013). Furthermore, given the current level of infrastructure spending, a persistent funding shortfall is preventing the closure of the so-called infrastructure gap (Woetzel et al., 2016). Tackling the infrastructure gap has therefore become the foremost global challenge for governments, because bridging this gap means to achieve economic recovery, sustainability and growth.

However, government efforts to meet this target on their own have been restricted by the austerity measures and budgetary constraints they faced after the recent global financial crisis of 2008 (Inderst, 2009). Nevertheless, institutional investors sit on trillions of cash that remain un-invested, despite the fact that infrastructure assets are thought to be an ideal match for institutional investors. The stable cash flows, the hedge against inflation and the low correlation of infrastructure assets with both macroeconomic conditions as well as other assets, should have guaranteed the participation of private investors in the infrastructure market and set the stage for rapid disappearance of the infrastructure gap. And yet, the gap persists despite infrastructure having received much attention in recent years from private investors (Authers, 2015). This concern was encapsulated in the first of three questions addressed in the present thesis. Why, despite the huge amount of capital available in the market, has the infrastructure gap not yet been bridged? We set out to examine the reasons behind the cautious attitude of private investors, and our findings in Table 9.1 convey that the availability and type of infrastructure financial mechanism should take account of, and be adaptable to, the needs of private investors. The illiquidity, the high management fees, the lack of transparency all present obstacles that turn private investors away from investing. Even though there are nowadays more private investors in the infrastructure market, these investments still require substantial regulatory guidelines and frameworks in order for them to advance. Regulatory conditions are therefore advocated as key levers for governments in enabling investment and attracting private sector participation. We have discussed propositions in this thesis that should help attract more private investment in infrastructure. For instance, the development of open-ended funds in the market could provide investors with more liquid access to infrastructure funds, the re-structuring of infrastructure funds could facilitate entry, the creation of Sovereign Wealth Funds can be used as a way of handling political risk, which is understood as a major obstacle to these investments, and last but not least, continued research on infrastructure assets will increase confidence, not only from the investor's perspective but also from the regulatory standpoint. Further evidence that verifies the stability and attractiveness of these investments could lead to more lenient regulation about these assets.

It is true that the increasing popularity of infrastructure investments from the private sector perspective has inspired scholars and practitioners alike to study the financial aspects of both listed and unlisted infrastructure (Finkenzeller et al., 2010, Inderst, 2009, Newell and Peng, 2008, RREEF, 2011). Thus, infrastructure has gained attention as a distinctive asset class that presents a new real opportunity for investors. Significantly, however, the financial characteristics of these investments has not been thoroughly analysed. As far as the purposes of the present thesis are concerned, the novelty of these investments and the lack of understanding of their performance profile has motivated a new literature stream. The author of this thesis was particularly keen to determine whether the asserted claims regarding infrastructure investments could be proved empirically. Studying and gaining deeper understanding of the behaviour of infrastructure investments

Table 9.1: Research approach summary, methodologies, results and impacts

Research Aims	Methodology	Research Results	Conclusions and Policy Recommendations	Chapter
- Examination of the mechanisms to support infrastructure private finance.	- Examine the availability, structure, and regulatory environment of private infrastructure finance	- Lack of confidence in relation to the financial characteristics of infrastructure assets. - Pension fund resources are still too fragmented. - Structure of infrastructure funds does not facilitate investors' appetite. - Political risks of infrastructure assets prevent the private sector participation. - Regulation that followed the financial crisis hinders private investments.	- Broader and in depth research agenda to assess infrastructure assets. - Initiatives to pool fragmented pension fund resources together. - Increase of 'split finance' model to stimulate greenfield investments. - Re-structuring of infrastructure financial mechanisms. - Creation of Sovereign Wealth Funds	4
- Financial examination of the underlying infrastructure EU and UK sectors and sub-sectors.	- Examination of annual returns, volatility, CVaR, CDaR, MAD, correlation benefits and Sharpe Index of different sectors and sub-sectors.	- Infrastructure sectors and sub-sectors show significant variation in their performance. - Some infrastructure sectors and sub-sectors are more defensive and illustrate more downside protection than traditional assets such as stocks and real estate.	- Listed infrastructure can certainly offer an attractive liquid opportunity for smaller pension funds and other retail investors aiming to access the infrastructure market without committing to a long-term illiquid investment.	5,6,7

Research Aims	Methodology	Research Results	Conclusions and Policy Recommendations	Chapter
- Evaluation of EU and UK infrastructure sectors at the portfolio level. - Focusing on a single EU infrastructure sector.	- Applying different optimisations (MVO, M-CVAR, M-CDAR, MAD) to test the construction of an infrastructure portfolio using an in-sample and an out-of-sample analysis.	- Infrastructure can benefit the institutional portfolio offering higher returns for the same level of risks particularly for less risk averse investors. - Focusing on the single sector and investing in several infrastructure sub-sectors can still offer diversification benefits while at the same time the investor can gain a deep understanding of the specific sector.	- If a country lacks investment in one particular sector, it can invest in this sector and still be able to diversify its infrastructure investment portfolio.	5,6,7
- Evaluating the financial performance of unlisted infrastructure funds. - Financial comparison of the listed and unlisted infrastructure market.	- Examination of annual returns, volatility, Sharpe Index and diversification benefits of the unlisted infrastructure funds. - Applying MVO to compare listed and unlisted infrastructure within the institutional portfolio.	- Unlisted infrastructure funds offer stable and strong financial performance with low volatility and strong diversification benefits among other financial assets. - Unlisted infrastructure outperforms its listed counterpart ,however, structural weaknesses and the lack of transparency of the unlisted infrastructure market prevents investors from investing largely in unlisted infrastructure funds.	- The unlisted infrastructure market must become more transparent. - Having a well-recognised benchmark in place will provide more confidence in this new asset class. - Illiquid of the funds can be addressed by having more open-ended funds in the market.	8

would represent the first step towards increasing investor participation. As mentioned in this thesis, investor confidence in relation to the financial behaviour of assets would have to come first.

Scholars and industry practitioners soon began testing the financial behaviour of the infrastructure asset class. For instance, the literature has studied, among other topics, the competitiveness of infrastructure within global traditional assets, its inflation hedging properties, its robustness during crises, and its significance in increasing diversification benefits in the institutional portfolio (and subsequently its impact when included in the traditional portfolio). Generally, the literature has been characterised by two main drawbacks. Firstly, given the established definition of infrastructure, most studies have failed to recognise the importance of heterogeneity within this asset class. Defining infrastructure in financial terms therefore requires a deep evaluation of its underlying sectors and sub-sectors. To this end, the second aim of the present thesis inquired into whether all infrastructure characteristics are shared by all infrastructure sectors and sub-sectors, and if not, set out to uncover the financial differences among infrastructure sectors or sub-sectors. The author conducted this analysis at both regional and country level. Furthermore, this thesis has focused on the significance of this differentiation at the portfolio level using different optimisation techniques in order to demonstrate how an effective and successful infrastructure portfolio can and should be constructed.

The second drawback faced by the literature is the absence of large available datasets in the market. The novelty of the infrastructure asset class makes robustness analysis a difficult and in some cases impossible task, particularly with regard to unlisted infrastructure. This factor has constrained much of the research in this field; and for this reason, this thesis has aimed to shed light on the financial performance of unlisted infrastructure assets using a comprehensive unlisted infrastructure index to examine the financial characteristics of investing in Unlisted infrastructure, its significance in the portfolio context, and to compare it to Listed infrastructure. All of the portfolio examinations in this thesis help us answer our third question: how should an infrastructure portfolio be constructed?

In addressing the second question of the thesis, the examination of the different infrastructure sectors and sub-sectors, it was observed that indeed failing to pay close attention to infrastructure sectors is not a robust analysis, as these sectors show substantial differentiation. In respect to the performance of infrastructure sectors to other traditional assets such as stocks, real estate and bonds, the thesis has confirmed many of the economic theories asserting that, due to the competitiveness of listed infrastructure companies and their ability to benefit from economies of scale and monopolistic structures they should to an extent offer better risk-adjusted returns, be more defensive, and offer better downside protection than other traditional assets. This was indeed confirmed in the present thesis, however, not for all infrastructure sectors and sub-sectors. The greater optimality of some infrastructure sectors in respect to others is significant enough to make an impact at the portfolio level. Additionally, the superiority of many infrastructure sectors and sub-sectors to other traditional investments was large enough to cause the replacement of stocks and real estate assets with certain infrastructure sectors and sub-sectors within the institutional portfolio. This was sharply observed in downside risk optimisation, which is important, because institutional investors such as pension funds aim not only to maximise risk-adjusted returns but also to protect their investments against high losses.

The heterogeneity of infrastructure sectors shows the significance of focusing and specialising in a single sector in order to understand the complexities inherent in specific sectors. This is the rationale behind our inquiry into how an infrastructure portfolio should be constructed, and whether one can focus on a single sector and still gain diversification benefits. By focusing on two substantially different infrastructure sectors, transport and energy, we wanted to observe whether it will still be beneficial to construct a portfolio comprised by a single sector. To analyse this idea in depth and to instil robustness in our results, we tested it using four different optimisation techniques. The results confirmed that even through specialisation, an investor can still obtain diversification benefits, because in our case infrastructure sub-sectors tended to behave differently, thereby allowing for the potential of diversification, even at sector level. This could have potentially significant implications not only at the investor level but also for fund managers, who could specialise and improve their understanding of the sector, and as a result more easily provide added-value to their infrastructure funds. Furthermore, this raises an exciting implication for governments as well, because if a nation lacks investment in one sector only, they can focus on that particular sector and still be able to diversify.

The findings of this thesis indicated that listed infrastructure is an optimal investment strategy for the less high risk-averse investors. Listed infrastructure is an ideal investment for investors who are willing to hold an optimal portfolio that bears more risk in exchange for higher returns. Highly risk-averse investors would take note to invest elsewhere, e.g., in a minimum risk portfolio.

The positive financial performance of listed infrastructure was confirmed in this research at both European and country level (United Kingdom). Importantly, one major advantage of listed infrastructure investments is the transparency that exists in this market. The extent of transparency in the listed infrastructure market is critical in allowing investors to focus on specific infrastructure sectors and sub-sectors; this outcome presents one of the main advantages of the listed infrastructure market, one that was not yet widely recognised, given that most scholars have failed to study the differences among sectors and sub-sectors. In contrast, this focus is nearly impossible to achieve in the unlisted infrastructure market due to scant empirical data and to the fact that fund managers do not share their strategies.

For this reason, the thesis investigated for the second time how an investor should construct an infrastructure portfolio, but this time with the aim to compare the two markets (listed and unlisted), and to ascertain whether the liquidity and rebalancing opportunities offered by the listed infrastructure market make it a better investment for the institutional portfolio. The results indicated that despite its current disadvantages, the financial performance of unlisted infrastructure investments offer superior risk-adjusted returns, thus making Unlisted infrastructure a more optimal strategy than Listed infrastructure. As part of the equity market, listed infrastructure is traded daily in large volumes. This gives listed infrastructure investments greater volatility than their unlisted counterparts. Having said that, it is prudent to recognise that unlisted infrastructure is not appropriate for every investor. For instance, in the case of pension funds that are unable to bear large liquidity risks or for other retail investors, listed infrastructure would provide an interesting opportunity, one that if examined correctly could outperform other traditional investments. With the still-wide infrastructure gap, listed infrastructure could be a solution to this knotty problem, by attracting a different kind of capital and inviting small pension funds and retail investors into the infrastructure market. On the other hand, for large institutional investors the attractive financial behaviour of unlisted infrastructure should be recognised as a perfect asset match. Given the attractive performance of these funds, private investments in the unlisted infrastructure market are not occurring at the rate they should due to the weaknesses we have discussed about the unlisted market.

In a further extension of the present research, one suggestion would be to examine the regulation(s) relative to these investments. A likely obstacle encountered when investing in infrastructure is Solvency II, which enforces higher capital requirements. Providing substantial evidence in the review process of Solvency II in 2018 could lead to amendments in Solvency II with regard to infrastructure assets. If substantial evidence were to be given on the risk profile of infrastructure investments, further changes could be made to Solvency II, thereby leading to more favourable treatment of infrastructure assets under Solvency II.

Solvency II introduces the Solvency Capital Requirement (SCR) risk measure defined as 'the potential decrease in the net asset value following a one-in 200-year event, over a one-year time horizon' (Saini and Haslip, 2011). Using a one-year approach, as proposed by Solvency II, treats insurance firms and pension funds as traders and subject to short-termism during phases of significant market volatility. Large institutional investors have long-term liabilities so they look to hold onto assets with long-duration to match their liabilities. This holds particularly true for their investments in infrastructure assets. There is preliminary evidence to indicate that a long-term approach can reduce solvency capital needs required compared to the one-year product (Jones, 2011). Of increasing relevance to this is the 'matching adjustment', introduced in Solvency II to avoid excess volatility. Under the matching adjustment, the risk-free rate used to discount the insurance liabilities is adjusted to allow falls in asset values to be balanced by decreases to insurers' liabilities, thereby allowing for a reduction of the required capital. However, this treatment is still questionable for certain infrastructure investments (Gatzert and Kosub, 2014). There are many restrictions and requirements for applying the matching adjustment, such as the requirement that assets should be of a sufficiently high quality, thus putting unrated or low-rated infrastructure bond investments in a minor position. Despite the improvements to the Solvency II regulation mentioned in Chapter 4 with regard to infrastructure investments, there are other improvements needed in order to guarantee that the regulation will not hinder private investment in infrastructure.

Another research suggestion is to examine an internal model to be used by the institutional investor instead of the Solvency II standard model. In this thesis we have identified the differences among infrastructure sectors, and although we found that the standard model does not distinguish between different infrastructure sectors, the use of a partial internal model could be more beneficial and adequate in presenting the true risk profile of these investments. Even if regulation stays the same, an insurance firm could provide its own internal model in which infrastructure is distinguished across different sectors and sub-sectors.

For the most part, the benefits of infrastructure investments in sustaining economic growth are widely recognised, and investing in infrastructure and bridging the infrastructure gap is a strategic priority for governments worldwide (Authers, 2015). The author is convinced that substantial insights and suggestions for unlocking private capital into infrastructure investments have been the main contributions of this thesis. Future research along the lines suggested above will certainly help to close the infrastructure gap once and for all.

Appendix A

Efficient Frontiers Sets for All the Portfolios of Chapter 5

Table A.1: Portfolio 1 includes only European traditional assets using mean-variance optimisation

Portfolio volatility (%)	Stock (%)	Government bonds (%)	Real estate (%) (%)	Portfolio return (%)
9.76	18.8	81.2	0	4.91
10.1	6.23	93.8	0	5.27
10.3	0	100	0	5.46
11.8	0	83.2	16.8	5.64
13.8	0	66.5	33.5	5.83
16.2	0	49.9	50.1	6.01
18.8	0	33.3	66.7	6.19
21.7	0	16.6	83.4	6.38
24.5	0	0	100	6.56

Table A.2: Portfolio 2 the same assets as Portfolio 1, plus the addition of all infrastructure sectors using mean-variance optimisation

Portfolio volatility (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
9.86	0	0	0	0	18.8	0	81.2	4.91
10.3	0	0	0	1.54	3.92	0	94.5	5.40
11.2	0	0	0	11.3	0	0	88.7	5.90
12.1	0	0	0	21.4	0	0	78.6	6.29
14.1	0	0	0.	36.6	0	0	63.4	6.88
15.8	0	0	0	49.3	0	0	50.7	7.38
17.7	0	0	0	62.0	0	0	38.0	7.87
19.8	0	0	0	74.7	0	0	25.3	8.36
21.8	0	0	0	87.3	0	0	12.7	8.86
23.8	0	0	0	100	0	0	0	9.35

Table A.3: Portfolio 2 the same assets as Portfolio 1, plus the addition of all infrastructure sectors using mean-conditional value-at-risk optimisation

CVaR (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
7.00	0	0	0	0	7.40	0	92.6	5.24
7.50	0	0	0	6.20	0	0	93.8	5.70
8.40	0	0	0	17.9	0	0	82.1	6.15
9.40	0	0	0	29.7	0	0	70.3	6.61
10.50	0	0	0	41.4	0	0	58.6	7.07
11.80	0	0	0	53.1	0	0	46.9	7.52
13.20	0	0	0	64.8	0	0	35.2	7.98
14.60	0	0	0	76.6	0	0	23.4	8.44
15.90	0	0	0	88.3	0	0	11.7	8.90
17.30	0	0	0	100	0	0	0	9.35

Table A.4: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean variance optimisation

Risk (%)	Fossil fuels (%)	Renewable energy (%)	Natural gas (%)	Electricity (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
10.0	0	0	6.36	2.49	14.6	0	76.6	4.16
10.1	0	0	7.18	11.6	6.31	0	74.9	4.44
10.3	0	0	7.70	21.2	0	0	71.1	4.73
11.2	0	0	7.09	37.2	0	0	55.7	5.15
11.7	0	0	6.87	43.1	0	0	50.0	5.30
13.0	0	0	6.46	54.0	0	0	39.5	5.59
14.4	0	0	6.05	65.0	0	0	29.0	5.87
16.1	0	0	5.63	76.0	0	0	18.4	6.16
17.8	0	0	5.22	86.9	0	0	7.87	6.44
19.7	0	0	0	100	0	0	0	6.74

Table A.5: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean-conditional value-at-risk optimisation

CVaR (%)	Fossil fuels (%)	Renewable energy (%)	Natural gas (%)	Electricity (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
3.30	0	0	11.8	2.83	3.81	0	81.6	4.28
3.30	0	0	14.5	11.3	0	0	74.2	4.55
3.50	0	0	15.9	21.0	0	0	63.1	4.82
3.70	0	0	14.6	31.8	0	0	53.6	5.09
4.10	0	0	15.5	41.7	0	0	42.8	5.37
4.50	0	0	13.1	53.1	0	0	33.9	5.64
5.00	0	0	14.8	62.6	0	0	22.6	5.91
5.60	0	0	13.3	73.5	0	0	13.2	6.18
6.10	0	0	14.3	83.4	0	0	2.35	6.46
6.80	0	0	0	100	0	0	0	6.74

Table A.6: Portfolio 4 includes transport sub-sector within a traditional portfolio using mean-variance optimisation

Risk (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
10.3	1.17	0	0	17.2	0	81.6	4.03
10.5	10.7	0	4.22	8.19	0	76.9	4.80
11.1	17.0	6.65	6.75	0	0	69.6	5.58
12.0	24.8	14.9	1.84	0	0	58.4	6.36
13.3	32.7	21.6	0	0	0	45.7	7.14
14.8	40.6	27.3	0	0	0	32.1	7.92
16.9	50.1	34.2	0	0	0	15.7	8.86
18.3	56.4	38.8	0	0	0	4.81	9.48
20.7	75.2	24.8	0	0	0	0	10.3
24.3	100	0	0	0	0	0	11.1

Table A.7: Portfolio 4 includes transport sub-sector within a traditional portfolio using mean-conditional value-at-risk optimisation

C-VaR (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
3.40	0	0	0	5.10	0	94.9	3.98
3.50	10.7	0	0.80	0	0	88.5	4.77
3.80	19.3	4.98	0	0	0	75.7	5.55
4.10	27.1	11.0	0	0	0	61.9	6.33
4.50	35.3	16.3	0	0	0	48.4	7.12
5.10	41.7	24.8	0	0	0	33.5	7.90
5.70	50.3	29.4	0	0	0	20.3	8.68
6.40	58.5	34.8	0	0	0	6.70	9.47
7.10	75.1	24.9	0	0	0	0	10.3
8.40	100	0	0	0	0	0	11.1

Appendix B

Efficient Frontiers Sets for All in-sample portfolios of Chapter 6

Table B.1: Portfolio 1 includes traditional assets and European infrastructure sectors using mean-variance optimisation

Risk (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
2.82	0	0	0	0	20.0	0	80.0	0.41
3.00	0	0	0	6.40	13.6	0	80.0	0.44
3.21	0	0	0	12.8	7.20	0	80.0	0.48
3.45	0	0	0	19.2	0.80	0	80.0	0.52
3.81	0	0	0	29.8	0	0	70.2	0.55
4.23	0	0	0	41.0	0	0	59.0	0.59
4.69	0	0	0	52.1	0	0	47.9	0.62
5.18	0	0	0	63.3	0	0	36.7	0.66
5.70	0	0	0	74.5	0	0	25.5	0.70
6.68	0	0	0	80.0	0	20.0	0	0.73

Table B.2: Portfolio 1 includes traditional assets and European infrastructure sectors using mean-variance optimisation using mean-conditional value-at-risk optimisation

CVaR (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
7.14	0	0	0	0	20.0	0	80.0	0.41
7.53	0	0	0	6.40	13.6	0	80.0	0.44
7.93	0	0	0	12.8	7.20	0	80.0	0.48
8.32	0	0	0	19.2	0.80	0	80.0	0.52
9.18	0	0	0	29.8	0	0	70.2	0.55
10.3	0	0	0	41.0	0	0	59.0	0.59
11.5	0	0	0	52.1	0	0	47.9	0.62
12.8	0	0	0	63.3	0	0	36.7	0.66
14.1	0	0	0	74.5	0	0	25.5	0.70
16.8	0	0	0	80.0	0	20.0	0	0.73

Table B.3: Portfolio 1 includes traditional assets and European infrastructure sectors using mean-variance optimisation using mean-conditional drawdown-at-risk optimisation

CDaR (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
21.9	0	20.0	0	0	0	0	80.0	0.45
24.1	0	10.9	0	9.1	0	0	80.0	0.48
26.2	0	1.73	0	18.3	0	0	80.0	0.51
30.6	0	0	0	27.8	0	0	72.2	0.54
36.2	0	0	0	37.5	0	0	62.5	0.58
42.1	0	0	0	47.1	0	0	52.9	0.61
48.1	0	0	0	56.7	0	0	43.3	0.64
54.7	0	0	0	66.4	0	0	33.6	0.67
61.8	0	0	0	76.0	0	0	24.0	0.70
83.4	0	0	0	80.0	0	20.0	0	0.73

Table B.4: Portfolio 1 includes traditional assets and European infrastructure sectors using mean-variance optimisation using mean-absolute deviation

MAD (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
2.09	0	0	0	0	21.4	0	78.7	0.40
2.24	0	0	0	5.89	14.1	0	80.0	0.44
2.43	0	0	0	12.4	7.65	0	80.0	0.48
2.63	0	0	0	18.8	1.18	0	80.0	0.51
2.91	0	0	0	29.2	0	0	70.8	0.55
3.23	0	0	0	40.5	0	0	59.5	0.59
3.56	0	0	0	51.8	0	0	48.2	0.62
3.93	0	0	0	63.1	0	0	36.9	0.66
4.32	0	0	0	74.4	0	0	25.6	0.70
4.98	0	0	0	80.0	0	20.0	0	0.73

Table B.5: Portfolio 2 includes transport sub-sector within a traditional portfolio using mean-variance optimisation

Risk (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
1.43	0	1.79	0	18.2	0	80.0	0.08
1.46	0	10.3	3.70	8.75	0	77.3	0.09
1.53	5.43	15.9	7.27	0	0	71.4	0.10
1.63	12.9	23.0	2.68	0	0	61.4	0.12
1.78	19.4	30.2	0	0	0	50.4	0.13
1.96	24.5	37.4	0	0	0	38.1	0.14
2.16	29.7	44.6	0	0	0	25.7	0.16
2.39	34.8	51.9	0	0	0	13.4	0.17
2.63	39.9	59.1	0	0	0	1.00	0.18
2.95	20.0	80.0	0	0	0	0	0.20

Table B.6: Portfolio 2 includes transport sub-sector within a traditional portfolio using mean-conditional value-at-risk optimisation

CVaR (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
3.55	0	3.64	1.05	15.3	0	80.0	0.08
3.61	0.18	11.6	5.03	3.22	0	80.0	0.09
3.78	4.55	20.0	0	0	0	75.4	0.11
4.07	9.59	27.0	0	0	0	63.4	0.12
4.45	14.1	34.4	0	0	0	51.6	0.13
4.92	24.8	38.3	0	0	0	36.9	0.14
5.45	28.0	46.3	0	0	0	25.7	0.16
6.02	31.0	54.4	0	0	0	14.7	0.17
6.61	32.6	63.4	0	0	0	4.08	0.18
7.34	20.0	80.0	0	0	0	0	0.20

Table B.7: Portfolio 2 includes transport sub-sector within a traditional portfolio using mean-conditional drawdown-at-risk optimisation

CDaR (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
21.6	16.8	0	0	3.25	0	80.0	0.09
25.5	33.0	0	0	0	0	67.0	0.10
31.3	49.7	0	0	0	0	50.3	0.11
38.4	54.3	6.62	0	0	0	39.1	0.12
46.2	59.5	12.9	0	0	0	27.6	0.14
54.3	65.1	18.9	0	0	0	16.0	0.15
62.4	69.3	25.7	0	0	0	4.97	0.16
70.8	60.2	39.8	0	0	0	0	0.17
80.3	40.1	59.9	0	0	0	0	0.19
91.9	20.0	80.0	0	0	0	0	0.20

Table B.8: Portfolio 2 includes transport sub-sector within a traditional portfolio using mean-absolute deviation optimisation

MAD (%)	Ports (%)	Airports (%)	Toll roads (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
1.00	0	2.46	0	21.3	0	76.2	0.08
1.03	0	10.6	5.21	13.2	0	71.0	0.09
1.09	5.29	16.8	7.13	7.01	0	63.7	0.10
1.16	11.6	22.6	8.38	0	0	57.4	0.12
1.26	19.2	29.3	4.86	0	0	46.6	0.13
1.37	23.8	38.0	0.15	0	0	38.1	0.14
1.49	29.3	45.2	0	0	0	25.9	0.16
1.62	36.7	50.9	0	0	0	12.4	0.17
1.77	39.7	59.3	0	0	0	1.04	0.18
1.99	20.0	80.0	0	0	0	0	0.20

Table B.9: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean-variance optimisation

Risk (%)	Natural gas (%)	Electricity (%)	Fossil fuels (%)	Renewable energy (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
1.41	8.53	0.23	0	0	13.9	0	77.4	0.08
1.42	9.51	8.17	0	0	6.61	0	75.7	0.08
1.44	10.5	16.2	0	0	0	0	73.3	0.09
1.49	11.4	25.6	0	0	0	0	63.0	0.09
1.58	12.3	34.9	0	0	0	0	52.8	0.10
1.72	13.1	44.3	0	0	0	0	42.6	0.10
1.88	14.0	53.6	0	0	0	0	32.3	0.11
2.07	14.9	63.0	0	0	0	0	22.1	0.11
2.27	15.8	72.4	0	0	0	0	11.9	0.12
2.49	20.0	80.0	0	0	0	0	0	0.12

Table B.10: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean-conditional value-at-risk optimisation

CVaR (%)	Natural gas (%)	Electricity (%)	Fossil fuels (%)	Renewable energy (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
3.36	14.8	0.08	0	0	5.12	0	80.0	0.08
3.37	14.1	8.77	0	0	0	0	77.2	0.08
3.47	16.7	16.7	0	0	0	0	66.6	0.09
3.69	19.9	24.3	0	0	0	0	55.7	0.09
4.00	18.3	34.4	0	0	0	0	47.2	0.10
4.34	24.6	40.5	0	0	0	0	34.9	0.10
4.72	27.1	48.5	0	0	0	0	24.4	0.11
5.14	26.8	57.9	0	0	0	0	15.2	0.11
5.62	23.6	68.9	0	0	0	0	7.52	0.12
6.10	20.0	80.0	0	0	0	0	0	0.12

Table B.11: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean-conditional drawdown-at-risk optimisation

CDaR (%)	Natural gas (%)	Electricity (%)	Fossil fuels (%)	Renewable energy (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
21.1	0	17.7	0	0	2.29	0	80.0	0.08
22.9	0.	25.4	0	0	0	0	74.6	0.09
26.1	0	33.5	0	0	0	0	66.5	0.09
30.4	0	41.6	0	0	0	0	58.4	0.10
35.7	0	49.7	0	0	0	0	50.3	0.10
41.3	0	57.8	0	0	0	0	42.2	0.10
46.9	0	65.9	0	0	0	0	34.1	0.11
52.6	0	74.0	0	0	0	0	26.0	0.11
58.5	4.18	80.0	0	0	0	0	15.8	0.12
64.9	20.0	80.0	0	0	0	0	0	0.12

Table B.12: Portfolio 3 specialises only in the energy sub-sector assets within a traditional portfolio using the mean-absolute deviation optimisation

MAD (%)	Natural gas (%)	Electricity (%)	Fossil fuels (%)	Renewable energy (%)	Stock (%)	Real estate (%)	Government bonds (%)	Return (%)
1.00	2.62	5.75	0	0	16.2	0	75.4	0.08
1.00	4.59	13.0	0	0	9.42	0	72.9	0.08
1.02	6.65	20.1	0	0	1.78	0	71.4	0.09
1.04	8.78	28.3	0	0	0	0	62.9	0.09
1.09	12.6	35.9	0	0	0	0	51.5	0.10
1.17	13.4	45.0	0	0	0	0	41.5	0.10
1.28	15.7	53.5	0	0	0	0	30.8	0.11
1.41	16.4	62.7	0	0	0	0	20.9	0.11
1.55	22.6	69.1	0	0	0	0	8.30	0.12
1.70	20.0	80.0	0	0	0	0	0	0.12

Appendix C

Efficient Frontiers Sets for All the Portfolios of Chapter 7

Table C.1: Portfolio 1 includes only United Kingdom traditional assets using mean-variance optimisation

Portfolio volatility (%)	Stock (%)	Government bonds (%)	Real estate (%) (%)	Portfolio return (%)
7.7	24.8	0	75.2	5.02
7.9	33.2	0	66.8	5.11
8.2	41.5	0	58.5	5.20
8.7	49.9	0	50.1	5.29
9.3	58.2	0	41.8	5.38
10.1	66.6	0	33.4	5.46
11.0	74.9	0	25.1	5.55
11.9	83.3	0	16.7	5.64
13.0	91.6	0	8.36	5.73
14.0	100	0	0	5.82

Table C.2: Portfolio 2 the same assets as Portfolio 1, plus the addition of all infrastructure sectors using mean-variance optimisation

Risk (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
7.57	2.8	11.4	0	0	12.7	0	73.1	5.12
7.99	0	19.7	0	6.61	7.66	0	66.0	5.54
8.91	0	24.5	0	16.3	0	0	59.2	5.96
10.3	0	27.0	0	25.1	0	0	47.8	6.38
12.0	0	29.6	0	34.0	0	0	36.4	6.80
13.8	0	32.2	0	42.8	0	0	25.0	7.22
15.8	0	34.8	0	51.7	0	0	13.5	7.64
17.9	0	37.4	0	60.5	0	0	2.11	8.06
20.3	0	20.9	0	79.1	0	0	0	8.48
23.4	0	0	0	100	0	0	0	8.90

Table C.3: Portfolio 2 the same assets as Portfolio 1, plus the addition of all infrastructure sectors using mean-conditional value-at-risk optimisation

CVaR (%)	Energy (%)	Telecom (%)	Utilities (%)	Transport (%)	Stock (%)	Real estate (%)	Government bonds (%)	Portfolio return (%)
4.28	2.00	14.6	0	0	0	1.93	81.4	5.04
4.60	0	22.5	0	3.40	7.99	0	66.1	5.47
5.71	0	26.6	0	13.7	0	0	59.7	5.89
6.99	0	35.0	0	19.8	0	0	45.2	6.32
8.47	0	48.2	0	23.4	0	0	28.4	6.75
10.0	0	62.1	0	26.7	0	0	11.3	7.18
11.8	0	63.9	0	36.1	0	0	0	7.61
13.8	0	42.6	0	57.4	0	0	0	8.04
16.0	0	21.3	0	78.7	0	0	0	8.47
18.3	0	0	0	100	0	0	0	8.90

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