# INFRASTRUCTURE INVESTMENTS –

# EMPIRICAL EVIDENCE ON AN EMERGING ASSET CLASS

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# 1 INTRODUCTION

## 1.1 GENERAL MOTIVATION

The term "infrastructure" refers to the backbone of each economy, which provides the basic goods and services to society, in order to promote economic and social welfare and development. Accordingly, infrastructure is typically defined in terms of the respective industrial sectors involved in the provision of these key essential services for the community. Specifically, infrastructure can be divided into economic and social. Whereas economic infrastructure includes the transportation, utilities and telecommunications sectors, social infrastructure typically comprises the health and educational sectors (Weber and Alfen, 2010). Due to factors such as climate change, growth, technological process and urbanization, the worldwide demand for new infrastructure is expected to expand significantly over the next few decades. Additionally, the existing infrastructure in countries of the Organization for Economic Co-operation and Development (OECD) is aging rapidly and therefore needs to be renewed, upgraded or maintained. Numerous studies attempt to quantify these future investment needs on a global basis. For instance, the OECD estimates approximately $71.1 trillion infrastructure investment demands by 2030 (OECD, 2006; OECD, 2007). More recently, the OECD even raised the number to $82.2 trillion (OECD, 2012), which corresponds to annual investment needs of nearly $3 trillion.

The mismatch between investment needs and financial resources is widely known as the "infrastructure gap" (Inderst, 2013). A study from the World Economic Forum (WEF) comes to the conclusion that the yearly global investment gap will amount to about $1 trillion (WEF, 2012). Needless to say, such large-scale investments cannot be financed solely by the public sector in times of constrained governmental budgets. Therefore, private capital may play a major role in addressing this issue, either in the form of corporate finance (operating infrastructure companies) or project finance (contractual financing arrangements) (Weber and Alfen, 2010). As a result, a new asset class labeled "infrastructure" has emerged in the financial markets and found its way into the portfolios of institutional investors in recent years, above all in those of insurance companies and pension funds. From a regional perspective, especially Australian and Canadian pension funds play a pioneering role in this field, with some of them allocating almost 10% of their assets to infrastructure (Croce, 2011).

Yet, there is a remarkable lack of academic research on infrastructure investments. However, more research would enhance the general understanding of this new asset class and thereby catalyze investment activity. To date, investors have to rely on almost only qualitative information concerning the attributes of infrastructure investments. The literature typically associates infrastructure investments with certain characteristics, such as an attractive risk/return profile, low correlation with the broader economy and other asset classes, diversification benefits, stable and predictable long-term cash flows with a good inflation hedge and low default rates (Inderst, 2013; Dechant *et al.,* 2010). However, very few of these alleged features have yet been quantified and empirically examined. Accordingly, the present dissertation aims at partially filling this very relevant research gap, thereby contributing to the emerging research stream on infrastructure investments. The dissertation consists of three papers and examines the inflation hedge characteristics, portfolio diversification benefits, as well as risk and return profile of infrastructure investments.

More precisely, the first paper investigates the inflation-hedging capacities of infrastructure and real estate investment vehicles. While it is generally assumed that direct infrastructure investments should represent a good hedge against inflation, no empirical evidence is yet available. Accordingly, the results are useful for long-term investors, who seek investment opportunities that are able to match their real liabilities. The second paper deals with a very current and relevant issue for European insurers. As mentioned, insurance companies have been among the most active infrastructure investors to date. However, with the introduction of the Solvency II Directive, investments in alternative asset classes, such as infrastructure and real estate, will be subject to higher capital charges. The paper therefore attempts to quantify to what extent the new Directive might constrain alternative asset allocations. Finally, the third paper considers the risk and return relationship of European listed infrastructure companies by running asset pricing models. Thus, this paper promotes an understanding of the pricing of listed infrastructure firms and is therefore helpful, both for investors as well as policy makers. The final section presents the main findings and provides an outlook for future research.

## 1.2 RESEARCH QUESTIONS

This section gives an overview of the course of analysis and the respective research questions for the three articles.

**Inflation Hedging and Protection Characteristics of**

**Infrastructure and Real Estate Assets**

- What is the theoretical justification that infrastructure investments provide a good inflation hedge?
- Is direct/listed infrastructure/real estate a hedge against expected and unexpected inflation in the short-run?
- Can direct/listed infrastructure/real estate investments hedge against actual inflation in the short-run?
- Is there a long-run relationship between inflation and direct/listed infrastructure/real estate investments?
- What are the short-run dynamics between asset returns and inflation?
- What is the inflation-hedging ability of infrastructure investments in comparison to real estate investments?
- Can listed/direct infrastructure/real estate investments offer desirable inflation protection characteristics?
- How does listed/direct infrastructure perform as an inflation-protecting asset in comparison to direct/listed real estate?

**Solvency II and Portfolio Efficiency –**

**The Case of Real Estate and Infrastructure Investments**

- What are the Solvency Capital Requirements (SCR) for real estate and infrastructure investments according to the Solvency II Directive?
- What roles do real estate and infrastructure assets play within the mixed asset portfolio of a representative European insurer?
- What are the optimal portfolio weights when portfolio optimization aims at minimizing portfolio risk?
- What is the optimal asset allocation when portfolio optimization aims at minimizing the capital charges according to the Standard Formula of the Solvency II Directive?

- Is there evidence of an incorrect parameterization of the Standard Formula that might affect the optimal weights in theory?
- Is overall portfolio efficiency affected by the introduction of Solvency II?
- What is the expected shift in infrastructure and real estate allocation when both optimization problems are accounted for simultaneously?
- Is it likely that the actual portfolio weights of real estate and infrastructure assets will be affected by the Solvency II Directive in practice?

**Can Common Risk Factors Explain Infrastructure Equity Returns? Evidence from European Capital Markets**

- Which stock market risk factors drive the returns of European listed infrastructure companies?
- Are traditional asset pricing models capable of explaining the shared variation in European infrastructure returns?
- Can additional bond market risk factors increase the predictability and quality of the asset pricing model?
- Are listed infrastructure companies sensitive to changes in interest rates?
- Do the risk factor loadings change in different market phases, i.e. when the sample is split into up- and down-markets?
- Are there sector-specific differences in the pricing of infrastructure firms?
- What could explain the the limited power of common asset pricing models used for infrastructure equities?

## 1.3 Course of Analysis

The following overview presents the chronology of the three articles, with regard to research design, authors and current publication status.

**Inflation Hedging and Protection Characteristics of**

**Infrastructure and Real Estate Assets**

The first article investigates the inflation-hedging and protection ability of direct and listed infrastructure and real estate investments over the period Q1 1991 to Q1 2013. Using a novel direct infrastructure performance index, this is the first study to answer this research question by employing the Fama and Schwert (1977) methodology and Engle and Granger (1987) co-integration tests. Moreover, causality tests, as well as shortfall-risk measure complete the empirical analysis.

Authors: Daniel Wurstbauer, Wolfgang Schaefers
Submission to: Journal of Property Investment and Finance
First Submission: 04/29/2014
Current Status: Published, Vol. 33, No. 1, 2015

*This paper was presented at the annual conference of the American Real Estate Society (ARES) in San Diego, 2014.*

**Solvency II and Portfolio Efficiency –**

**The Case of Real Estate and Infrastructure Investments**

The second paper examines the potential effect of the Solvency II Directive on the portfolio efficiency, and real estate and infrastructure allocation of European insurers. The innovative methodology introduces a capital budget restriction into the traditional Markowitz (1952) portfolio algorithm, in order to quantify the potential practical impact of the Directive.

Authors: Michael Heinrich, Daniel Wurstbauer
Submission to: Journal of Risk and Insurance
First Submission: 05/06/2015
Current Status: Under Review

*This paper was presented at the annual conference of the European Real Estate Society (ERES) in Bucharest, 2014.*

**Can Common Risk Factors Explain Infrastructure Equity Returns?**

**Evidence from European Capital Markets**

The last paper of the dissertation runs the well-known Fama and French (1993) asset pricing models, including stock market risk factors, as well as bond market risk factors in order to test whether these factors are able to explain the excess returns of infrastructure firms. To answer this research question, this paper is built on a dataset of all listed European infrastructure companies, which had to be identified first, using an elaborate screening process.

Authors: Daniel Wurstbauer, Stephan Lang, Christoph Rothballer, Wolfgang Schaefers
Submission to: Journal of Property Research
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Current Status: Under Review

*This paper was presented at the annual conference of the American Real Estate Society (ARES) in Fort Myers, 2015 and at the annual conference of the European Real Estate Society (ERES) in Istanbul, 2015.*

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# 2 Inflation Hedging and Protection Characteristics of Infrastructure and Real Estate Assets

**Purpose** – Similar to real estate, infrastructure investments are regarded as providing a good inflation hedge and inflation protection. However, the empirical literature on infrastructure and inflation is scarce. Therefore, we investigate the short and long-term inflation-hedging characteristics, as well as the inflation protection associated with infrastructure and real estate assets.

**Design/methodology/approach** – Based on a unique dataset for direct infrastructure performance, a listed infrastructure index, common direct and listed real estate indices, we test for short and long-term inflation-hedging characteristics of these assets in the U.S. from 1991-2013. We employ the traditional Fama and Schwert (1977) framework, as well as Engle and Granger (1987) co-integration tests. Granger causality tests are further conducted, so as to gain insight into the short-run dynamics. Finally, shortfall risk measures are applied to investigate the inflation protection characteristics of the different assets over increasingly long investment horizons.

**Findings** – The empirical results indicate that in the short-run only direct infrastructure provides a partial hedge against inflation. However, co-integration tests suggest that all series have a long-run co-movement with inflation, implying a long-term hedge. The causality tests reveal reverse unidirectional causality – while real estate asset returns are Granger-caused by inflation, infrastructure asset returns seem to cause inflation. These findings further confirm that both assets represent a distinct asset class. Ultimately, direct infrastructure investments exhibit the most desirable inflation protection characteristics among the set of assets.

**Research limitations/implications** – This study only presents results based on a composite direct infrastructure index, as no sub-indices for sub-sectors are available yet.

**Practical implications** – Investors seeking assets that are sensitive to inflation and mitigate inflation risk should consider direct infrastructure investments in their asset allocation strategy.

**Originality/value** – This is the first study to examine the ability of direct infrastructure to assess inflation risk.

## 2.1 Introduction

Inflation has long been identified as a major risk for individual investors, especially for those who aim to match their real liabilities through the investment process. Although inflation rates have been relatively low in the past few decades, the influence of inflation on invested capital needs to be addressed by investors with a long-term investment horizon. In addition, inflation may well be on the rise over the next few years, due to the generally loose money policy in the aftermath of the financial crisis. Therefore, inflation is certainly back on the agenda and investors seek opportunities with inflation-hedging characteristics to add to their mixed-assed portfolios in order to counter inflation risk.

Real estate investments have traditionally been perceived as a good inflation hedge and constitute a decisive share of institutional investors' portfolios. This is attributable mainly to the fact that the nominal cash flows of real estate assets are either contractually linked to inflation or can be renegotiated from time to time. As a consequence, investors are able to adjust the cash flows in line with the changes in the price level. More recently, there has been a growing interest in alternative asset classes, such as infrastructure, and investors seek to expand their allocation of such assets within their portfolio (Mercer, 2012; Dechant *et al.,* 2010). Investors thereby perceive infrastructure rather as a complement than as a substitute for real estate. Studies suggest that most of the institutional investors already place infrastructure in a specific infrastructure allocation and only very few place it with real estate. Besides that, infrastructure is also sometimes categorized as "inflation-hedged" or a "real asset" (Probitas Partners, 2011). The significance of a separate allocation is affirmed by recent asset allocation studies which show that listed infrastructure (Oyedele *et al*., 2014) as well as direct infrastructure (Dechant and Finkenzeller, 2013) are not a substitute for real estate within the mixed-asset portfolio and therefore should be included. Both studies conclude that infrastructure helps to reduce the portfolio risk rather than to increase overall portfolio performance.

In general, infrastructure investments can be divided into two main categories: economic and social. Whereas economic infrastructure investments comprise assets in the transportation, energy, water, gas and communications sectors, social infrastructure investments typically compromise assets in the healthcare or education sectors (Wagenvoort *et al*., 2010; Weber and Alfen, 2010). [1] Hence, real estate and infrastructure share some technical characteristics, such as indivisibility and tangibility. Similar to real estate, the cash flows generated by infrastructure assets are often contractually or regulatorily linked to inflation. Moreover, infrastructure assets are regarded as resilient to inflation on account of their specific characteristics, such as high replacement costs, high pricing power and a low share of operating costs after initial construction

(Croce, 2011). Consequently, infrastructure investments may constitute a further desirable investment alternative for institutional investors as a means of accounting for inflation. This argument is backed by recent surveys among institutional investors, which reveal that the desire to invest in assets with inflation-hedging characteristics is one of the most important drivers of infrastructure investments (Probitas Partners, 2013).

While there is already a broad body of literature on the linkage between real estate and inflation, there are only few studies examining the inflation-hedging characteristics of infrastructure investments. Moreover, the empirical findings so far are limited to listed infrastructure investments due to the absence of reliable and accessible performance data for direct investments. Interestingly, the findings so far suggest that listed infrastructure is not a good hedge against inflation which contradicts the general belief and expectations of investors. However, the primary route for investors to gain exposure to infrastructure is via unlisted funds or direct investments (Preqin, 2014) and no empirical evidence is available that might help investors to evaluate their expectations. Therefore, the main objective of this paper is to fill the empirical gap on (direct) infrastructure investments and its relationship to inflation in order to help investors to better understand the asset class towards its inflation-hedging ability. By means of a unique dataset of U.S. direct infrastructure performance, which was first used by Dechant and Finkenzeller (2013), we are able to employ commonly used methods from the finance and real estate literature in order to examine the inflation-hedging and protection effectiveness of infrastructure assets. We further include listed infrastructure, direct and listed real estate data in our analysis, in order to compare the results between the two asset classes, as well as with the existing empirical literature.

We employ the traditional Fama and Schwert (1977) framework to analyze short-term hedging ability with respect to expected and unexpected inflation. In addition, we conduct Engle Granger (1987) co-integration tests to assess the long-term relationship between asset return series and inflation and run Granger causality tests to investigate the short-run dynamics. A common shortcoming of the traditional approaches is that they only capture the co-movement between asset returns and inflation and therefore explain only a small fraction of the total variance in nominal returns. To address this shortcoming, we further examine the level of inflation protection by calculating downside-risk measures for the respective asset returns. We thus assume that investors are more interested in achieving a positive real return for a given investment period than simply a co-movement with inflation.

The remainder of this paper is structured as follows. Section 2 describes the theoretical background and intuition on infrastructure and inflation in order to enhance the general understanding of the asset class itself. Section 3 gives a brief overview of the relevant literature on infrastructure, real estate and inflation. The methodologies applied in this paper are explained in Section 4. Section 5 presents the data used in the empirical analysis. Next, the empirical results are discussed in Section 6 and the final section concludes.

## 2.2 Intuition on Infrastructure and Inflation

Most of the (industry) publications on infrastructure explicitly state the potential of infrastructure assets for protecting against inflation (Inderst, 2009; RREEF 2005, 2007; Colonial First State, 2006; Croce, 2011; Probitas Partners, 2012). Generally, this ex-ante claim is justified theoretically by the specific cost and revenue characteristics that are associated with infrastructure assets. Similar to real estate, infrastructure is a tangible asset and therefore, the increasing replacement costs of real assets should protect the value of existing assets in an inflationary environment (Gray, 2009). Moreover, the operating costs only account for a small share of total costs after the initial construction (Martin, 2010). In addition, other input costs that are affected by inflationary increases, such as commodities, salaries or maintenance, can often be passed on to customers. This is either the case due to low price sensitivity, as infrastructure services are an essential good, or due the prevailing regulatory regimes (RREEF, 2005).

However, infrastructure should not fundamentally be seen as a tangible asset per-se, it is the contractual agreement of the underlying asset that creates the value of a particular infrastructure investment. This challenges the conventional belief that infrastructure assets are real assets. The physical long-term nature of infrastructure therefore rather leads to the necessity of long-term contracts. In addition, infrastructure investments do not even necessarily include physical ownership of the respective asset, as it is the case with most public private partnerships (PPP) in the transport or health sector. As a result, the future cash flows of infrastructure assets are predominantly based on contractual claims (Blanc-Brude, 2013). The extent of inflation protection ability generated by infrastructure assets therefore depends on the specific type of infrastructure asset, the industry subsector or whether the revenue is regulated by contract or agency. As a consequence, if the contractual agreements do not account for inflation risk, the asset is fully exposed to inflationary influences despite the alleged real asset nature.

Revenues regulated by contract can be based either on a user-financed model (private partner is allowed to collect user fees) or budget-financed model (private partner receives fixed payments from the public sector, e.g. availability payments) (Weber and Alfen, 2010). In both cases, the revenue streams are typically linked to inflation, either due to permitted toll increases (user-financed) or index-linked availability payments (budget-financed). Revenues regulated by agency, on the other hand, refers to permitted tariff increases or returns on equity that are linked to inflation. Accordingly, as mentioned above, the operating and maintaining costs can be transferred to the user and hence, the operator/investor is able to achieve a stable real rate of return. However, these increases are capped, so that the operator/investor is not able to abuse the monopolistic situation in which the asset often operates (Armann and Weisdorf, 2008). There are also infrastructure assets without an explicit link to inflation, but high pricing power, so that a similar outcome can be achieved (Colonial First State, 2011).

To understand the linkage of different, heterogonous infrastructure assets with inflation, it is necessary to investigate the specific subsectors separately. Therefore, we highlight below several selected economic and social infrastructure sectors and the respective connection between their revenues and inflation.

As pointed out in the introduction, economic infrastructure generally comprises infrastructure assets in the transportation, utilities (electricity, water, gas) or communications sector. Toll roads represent a prominent example of a transportation infrastructure asset. The typical business model for a toll road is a long-term concession agreement between a governmental authority and a private operator that explicitly allows the operator to increase tolls in line with inflation (user-financed). Furthermore, most operators are able to negotiate an additional margin in order to compensate for capital expenditures, such as new sections (Weisdorf, 2007). If such concession agreements do not exist and the roads operate under a PPP, the government authority makes an availability payment (budget-financed) to the operator, which is mostly based on a certain inflation indexing mechanism (e.g. Port of Miami Tunnel with availability payments that provide 85% inflation indexation) (Eagar, 2008; RBC, 2011).

Assets in the electricity, water and gas utilities sector are mostly pure (regional) monopolies and therefore, pricing is regulated by a government-appointed regulator. This requires formal processes to set an appropriate rate which utilities are allowed to charge consumers for their services. Hence, there are several factors that the regulators have to account for when negotiating and determining a new rate. Examples are customer base, consumption growth, capital expenditures, interest rates on debt costs and ultimately inflation. As a consequence, regulators may increase rates with inflation to allow for a higher return on equity for regulated utilities, thus protecting their real earnings (Eagar, 2008; RBC, 2011). The development of rates for listed electric companies in the U.S., for instance, is summarized in the quarterly "Rate Case Summary" of the Edison Electric Institute (EEI). The average quarterly awarded return on equity (ROE) is around 10% (Q2 2013), with an average regulatory lag of 11.8 months between rate case filing and decision. For instance, in a recent rate case, San Diego Gas & Electric was allowed to increase its rates based on the Consumer Price Index (EEI, 2013). In addition, the renewable energy sector (e.g. wind, solar, hydro etc.) has been emerging in the U.S. in recent years. Renewable power purchase agreements may have so-called "feed-in-tariff" (FIT) regimes which are basically payments to the generator of renewably energy. That is, the government sets prices that the regulated utilities have to pay to the generators for the energy generated and for being connected to the grid. In this manner, inflation is either already incorporated into the initial tariff or the tariffs are (fully) indexed to inflation. Gipe (2010) grades the North American FIT's and thereby explores only partial inflation indexing with the few existing FITs in the U.S. However, besides the FIT regimes, there are also several privately negotiated or regulated power purchase agreements and other utility concession agreements with similar inflation adjustment mechanisms (RBC, 2011). It is important to note that pure energy production assets are not always considered as typical infrastructure investments, as they can also operate in competitive markets (Inderst, 2013). However, this is generally not the case for assets in the alternative energy sector with FIT-regimes.

In the communications sector, telecom service providers typically lease broadcast communication towers for 5-15 years, with multiple renewal options and contracted annual price escalators of 3-5%. Generally, the number of communication assets, especially mobile towers, is limited due to strict zoning requirements and resentment on the part of residents. As a consequence, the barriers to entry are particularly high in this sector, which provides the tower industry with considerable pricing power. Accordingly, the contract renewal rate in the communication sector is also very high. Overall, assets in the communication sector are therefore regarded as resilient to inflation (Colonial First State, 2011).

Social infrastructure investments typically include PPPs in schools, hospitals or other health facilities. Likewise, for PPPs in the transportation industry, the public sector enters into an availability payment contract with a private partner (operator) that includes explicit payment increases in line with inflation. The degree of inflation linkage may vary, as PPP contracts are not necessarily standardized, depending upon the stage of PPP regimes. As the U.S. is in a relatively early stage in this context, it might be the case that the inflation linkage in PPP contracts varies. Besides a direct, contractually adjusted formula, some operators also embed their inflation expectations into the pricing of availability payments over the life of the contract, thus creating some degree of inflation protection (RBC, 2011). In general, PPPs in the social infrastructure sector (as well as in other sectors) are believed to deliver stable real returns, not only due to fixed income payments with explicit inflation linkage. They also offer a stable real return, since construction risk, as well as operations and maintenance costs, are usually passed on contractors and subcontractors (Blanc-Brude, 2012). Furthermore, deductions from the charges that can be made in case of service delivery failure are rare and small, so that the overall capital structure is unlikely to be negatively affected, i.e. debt repayment and equity distribution is assured (Ipsos MORI Social Research Institute, 2009).

Taking all these examples together, it is evident that there is a theoretical justification for infrastructure investments offering attractive inflation-hedging and protection characteristics in general. However, this theoretical potential may not vary only by sector, and other practical risks may influence the amount of inflation-hedging realized by an investor in infrastructure assets. Firstly, the cash flows of infrastructure investments are considerably influenced by the nature of the underlying revenue scheme. While the cash flows from projects with availability payments schemes are not subject to revenue risk, budget-financed or regulated assets are due to their exposure to demand risk. Moreover, operational risks (e.g. maintenance cost) and political/regulatory risks (e.g. legal changes, contract negotiation) influence the revenues depending on the risk-sharing mechanisms used between the public and the private sector (Blanc Brude, 2013; Grimsey and Lewis, 2002). In addition, it is crucial whether only revenue or also expenses are linked to inflation. Moreover, the extent (limitations, caps) and timing of adjustments to inflation can influence the hedge against inflation (Rödel and Rothballer, 2012). As infrastructure investments typically exhibit high levels of gearing, inappropriate capital structures can lead to poor equity performance, despite good underlying asset quality. Hence, the management of debt exposure is of considerable significance for infrastructure assets. However, the extent of vulnerability to increasing borrowing costs differs by sector. While utilities can recover the variable borrowing costs through the periodic regulatory process, assets in other sectors need to be hedged with interest swaps or similar instruments, so as to ensure that the inflation-linked revenue increases flow-through to the investor (Eagar, 2008). A further explanation of a weak linkage to inflation is that the individual cost base of infrastructure companies does not correspond to the CPI goods basket thus, eroding the potential inflation hedge. Moreover, prices are sometimes linked to related inflation measures, such as construction costs, that are not necessarily perfectly correlated with the CPI (Armann and Weisdorf, 2008). In the case of infrastructure investments outside the home country, this mismatch can also occur due to different metrics for measuring inflation and exchange rate fluctuations. This can be the case particularly with listed infrastructure investments, as some infrastructure companies may also own and operate infrastructure assets abroad (RBC, 2011).

We therefore expect infrastructure investments to constitute a hedge against inflation. However, the inflation-hedging ability might differ between direct and listed infrastructure investments, due to certain practical risks, such as the location of the asset or leverage. While direct investments in infrastructure are per se U.S.-based, listed companies might also operate internationally. Moreover, the direct performance data used in the analysis is not subject to leverage, whereas listed companies in fact exhibit high levels of gearing. As a consequence, the short-run co-movements might be distorted. Hence, we also investigate the long-run relationship, as well as the inflation protection ability of infrastructure assets and expect both infrastructure assets to provide desirable long-term features.

## 2.3 LITERATURE REVIEW

In this section, we focus mainly on currently available empirical evidence on the relationship between infrastructure assets and inflation. As there are many studies covering both direct and listed real estate investments and the results are rather diverse, we refer to Hoesli *et al.* (2008), Park and Bang (2012) and Obereiner and Kurzrock (2012) for a current and exhaustive literature review on the inflation-hedging ability of real estate. In general, the results differ mainly according to the data, methodology, market and time horizon. In summary, the more recent literature states that both listed and direct real estate investments generally do not hedge against inflation in the short-run. The results for the long-run relationship are more diverse, but there seems to be a long-term relationship between real estate assets and inflation. Concerning inflation protection, Hamelink *et al*. (1997) and Maurer and Sebastian (2002) investigate the inflation protection of direct and/or listed real estate investment vehicles and both obtain relatively similar results. They find that real estate investments in general show the well-known time diversification effect, i.e. the probability of a negative real return for longer investment periods decreases. Maurer and Sebastian (2002) further investigate the German open-ended funds market and find superior inflation protection attributes compared to other listed real estate vehicles.

As already mentioned, empirical research on the interrelation between infrastructure and inflation is rare and often limited to industrial rather than academic research. Moreover, listed infrastructure data is often used as a proxy for general infrastructure performance. RREEF (2008), for instance, find some evidence of a positive correlation (0.34) between the UBS Infrastructure & Utilities index and inflation in the U.S. However, the positive correlation coefficients are relatively low, especially for the subsets of different infrastructure sectors (ranging from -0.24 to 0.24), and no significance test have been run to validate the results. Employing historical performance data from Mercer, relating to five major Australian infrastructure funds, Colonial First State (2007) calculates the average real returns for different holding periods, showing positive returns throughout. Hence, infrastructure investments seem to offer inflation protection. Similarly, JP Morgan (2009) analyzed the annual cash-flows of 256 mature infrastructure assets in the U.S. and

Europe from 1986-2006. The equally weighted portfolio of these assets grew steadily above inflation, which also indicates that infrastructure assets can provide effective protection against inflation in the long-run.

In one of the first academic studies, Peng and Newell (2007) investigate the listed and unlisted Australian infrastructure market, with unlisted infrastructure being represented by an expanded and updated data set of Australian infrastructure funds, compared to that of Colonial First State (2007). Over the time period from 1995-2006, they find surprisingly negative (-0.20 for listed and -0.27 for unlisted infrastructure), but insignificant correlations for both listed and unlisted infrastructure investments. Furthermore, Martin (2010) also detects either no correlation or even negative correlations for most of the listed infrastructure sectors and utilities in the U.S. Only the energy sector shows evidence of a positive correlation with the CPI. In contrast, Sawant (2010) identifies slightly positive correlations (ranging from 0.09 to 0.11) of three international infrastructure equity indices with U.S. inflation. However, the results are debatable, as they are not statistically significant and the international indices cover a decisive number of firms outside the U.S. Using annual cash flows (EBITDA) of U.S. regulated infrastructure assets, concessions and electricity generation assets instead of equity indices, Armann and Weisdorf (2008) find a positive correlation coefficient of 0.35 between infrastructure cash flows and U.S. inflation represented by the CPI, again implying a potential inflation hedge.

There are only a few empirical studies that use more sophisticated statistical methods to examine the inflation-hedging characteristics of infrastructure investments. Bitsch *et al.* (2010) use a broad sample of global infrastructure deals to investigate the performance drivers of unlisted infrastructure returns. Among other variables, they include inflation in the regression and find a positive relationship. However, no definite conclusion can be drawn, since the coefficient is not statistically significant and they also do not account for the specific inflation rates in the respective countries, i.e. the U.S. inflation rate is used as an inflation proxy for all deals outside the European Union. More recently, Bird *et al.* (2014) investigate the listed Australian and U.S. infrastructure market by means of the frequently used UBS Infrastructure & Utilities index for each country, as well as the unlisted Australian market in the form of updated data used by Peng and Newell (2007). They find that the listed U.S. utility sector displays sensitivity to inflation-linked bonds (TIPS), as well as the composite indices (infrastructure and utilities) of both sectors. The pure infrastructure indices and the unlisted series, in turn, show no significant inflation- hedging ability. Ultimately, Rödel and Rothballer (2012) examine a broad sample of more than 1.400 listed infrastructure companies across 45 countries with regard to their inflation-hedging ability. They find that infrastructure equities do not hedge inflation more effectively than general equities, that is, not particularly well. Only a subsample of companies with high pricing power yields some evidence of inflation hedge on a five-year horizon.

In summary, research on the relationship between inflation and infrastructure is still limited and generally covers only the listed infrastructure universe. Furthermore, most studies only scratch the surface of inflation-hedging ability in the course of a more general analysis, rather than conducting a dedicated study on the issue. Ultimately, there is no research so far on the direct infrastructure universe that is based on a meaningful available benchmark.

## 2.4 Methodology

### 2.4.1 OLS Regression Model

To test the short-term inflation-hedging ability of the asset returns, we run different regression models. We apply the traditional Fama and Schwert (1977) framework, which is based on the Fisher (1930) hypothesis. Fisher states that the nominal interest rate equals the sum of the expected real interest rate and expected inflation. Assuming that expected real returns depend solely on real factors, thus not correlating with expected inflation, the return-inflation relation can be investigated without a complete general equilibrium model. Fama and Schwert (1977) decompose inflation into its expected and unexpected components:

$$R_{jt} = \alpha_{\mathrm{j}} + \beta_j E(\Delta_t|\phi_{t-1}) + \gamma_{\mathrm{j}}[\Delta_t - \mathrm{E}(\Delta_t|\phi_{t-1})] + \eta_{\mathrm{jt}} \quad (1)$$

Where $R_{jt}$ is the nominal return of the respective asset, $E(\Delta_t|\phi_{t-1})$ represents expected inflation, given the information available in $t-1$, and $[\Delta_t - \mathrm{E}(\Delta_t|\phi_{t-1})]$ represents unexpected inflation. Unexpected inflation is determined by simply subtracting expected inflation from actual inflation. According to Fama and Schwert (1977), an asset provides a hedge against expected or unexpected inflation, when $\beta_j$ or $\gamma_{\mathrm{j}}$ is statistically indistinguishable from unity. If both regression coefficients equal unity, the asset provides a complete hedge against inflation. In turn, an asset is seen to be a partial hedge if the $\beta_j$ and $\gamma_{\mathrm{j}}$ are less than 1.0, but distinguishable from zero. The signs of the regression coefficients imply whether the asset is a positive or negative hedge.

To test the robustness of our results, we follow Gültekin (1983) and examine whether real estate and infrastructure assets are an effective hedge against actual inflation. This implies that inflation expectations are perfect and that the actual inflation rate equals expected inflation. The model is given by:

$$R_{jt} = \alpha_{\mathrm{j}} + \beta_j \Delta_t + \varepsilon_{jt} \tag{2}$$

where $R_{jt}$ is the nominal return of the respective asset, $\Delta_t$ is the actual rate of inflation in period $t$ and $\varepsilon_t$ the error term. The intercept $\alpha_{\mathrm{j}}$ can be interpreted as the real rate of return of the asset.

The choice of proxy for expected inflation is crucial when testing the inflation-hedging ability, as the results may differ substantially (see e.g. Stevenson and Murray, 1999). Common proxies are lagged treasury bills (mostly 1-month or 3-month), assuming constant real interest rates or time-varying real interest rates. Real interest rates can be forecasted either via moving average processes (Fama and Gibbons, 1984) or autoregressive integrated moving average models (ARIMA) (e.g. Gültekin, 1983). More recent studies test different ARIMA models based on past inflation (e.g. Hoesli *et al.,* 2008) to estimate the best proxy. Ultimately, surveys and publicly available forecasts can also be used as proxies and are probably the most directly observable inflation expectations. We test a range of different expected inflation proxies for their goodness, as proposed by Stevenson (2000), and use the best proxy for further calculations. Details are presented in the data section.

### 2.4.2 Co-Integration and Granger Causality Tests

The static OLS methodology has frequently been used to test the inflation-hedging ability of several asset classes. However, this static approach can only capture the short-term dynamics, without taking into account a possible underlying long-term relationship between the assets and inflation. As infrastructure and real estate assets are typically long-term investments with several common features, such as illiquid underlying assets and lengthy transaction periods, it is essential to distinguish between the short-term and long-term effects. Therefore, we use co-integration methodology to assess the long-term inflation-hedging ability of infrastructure and real estate assets. The two-step procedure proposed by Engle and Granger (1987) is employed in this paper, as we wish to test the pair-wise co-integration between infrastructure or real estate and inflation. Following Tarbert (1996), we do not distinguish between expected and unexpected inflation and use ex-post actual inflation. All series are tested for stationarity, using the augmented Dickey Fuller (ADF) test. The test regression is given by:

$$\Delta Y_t = \alpha + \alpha_1 Y_{t-1} + \alpha_2 t + \sum_{j=1}^{p} y_j \Delta Y_{t-j} + \varepsilon_t \tag{3}$$

where $Y$ is the series (total return index or CPI) examined, $t$ is a trend variable and $\varepsilon_t$ is the error term.

In order to test for co-integration, all series must be non-stationary with respect to level, but stationary for first-differences. Accordingly, all series must be integrated of the same order, that is, I(1). Next, the two non-stationary time series are regressed on each other:

$$Y_t = \alpha + \beta X_t + u_t \tag{4}$$

where $Y$ is the return series (index) examined and $X$ is the inflation series (index). The residuals $u_t$, as a linear combination of the two non-stationary variables, are recovered and subsequently tested for stationarity, using the ADF test without trend and without constant.

$$\Delta\hat{u}_t = \alpha * \hat{u}_{t-1} + \sum_{j=1}^{m} \phi_j \Delta\hat{u}_{t-j} + \nu_t \tag{5}$$

If the residuals are stationary in level, the two series are said to be co-integrated and therefore exhibit a long-term relationship. The critical values for this unit root test are calculated according to MacKinnon (2010), since the tested residuals are not observed, but estimated values. Hence, the critical values differ slightly.

Following the co-integration tests, we conduct Granger causality tests to examine the direction of causality between inflation rates ($I_t$) and asset returns ($R_t$) and whether inflation helps to predict the asset returns or vice versa. If the variables are not co-integrated, the model can be written as:

$$R_t = \alpha_1 + \sum_{i=1}^{n} \beta_{1i} R_{t-i} + \sum_{i=1}^{n} \gamma_{1i} I_{t-i} + \varepsilon_{1t} \tag{6}$$

$$I_t = \alpha_2 + \sum_{i=1}^{n} \beta_{2i} R_{t-i} + \sum_{i=1}^{n} \gamma_{2i} I_{t-i} + \varepsilon_{2t} \tag{7}$$

If there is evidence of co-integration between the asset series and inflation, an error correction term $E_{t-1}$ must be included in the causality tests. The so-called Granger causality-error correction model is then given by:

$$R_t = \alpha_1 + \sum_{i=1}^{l} \beta_{1i} R_{t-i} + \sum_{i=1}^{l} \gamma_{1i} I_{t-i} + \delta_1 E_{t-1} + \varepsilon_{1t} \tag{8}$$

$$I_t = \alpha_2 + \sum_{i=1}^{l} \beta_{2i} R_{t-i} + \sum_{i=1}^{l} \gamma_{2i} I_{t-i} + \delta_2 E_{t-1} + \varepsilon_{2t} \tag{9}$$

The error correction term is added as an error correction mechanism for the long-run equilibrium relationship between the asset return series and inflation. In accordance with the co-integration tests, we use actual inflation instead of expected and unexpected inflation. To test the causal relationship, a joint test of the significance of $\gamma_{1i}$ or $\beta_{2i}$ using F-statistics is conducted.

### 2.4.3 Inflation Protection

Investors are not interested only in whether or not nominal asset returns co-move with inflation (inflation hedge), but rather seek investments with a long-term protection against inflation. As many additional risk factors may cause variations in nominal asset returns, the complete hedging ability of an asset does not necessarily imply that the downside risk of a negative real return can be neglected. Therefore, inflation protection needs to consider whether an asset provides a positive real return over a given investment period, so that purchasing power is retained.

The concept of inflation protection is essentially a shortfall risk measure indicating that the return of an asset may not achieve a desired target return. In terms of inflation protection, this target return is represented by the actual rate of inflation, meaning that the real return of an asset should exceed a 0% return over a given investment period. Among others, Estrada (2006) notes that investors associate risk rather with negative returns or returns below their expectations than with unexpected large positive outcomes. Accordingly, downside (or shortfall) risk measures have gained more and more attention from both academia and practitioners over the past few years.

In real estate research, downside risk measures have mainly been incorporated into asset allocation frameworks, e.g. Sing and Ong (2000) or Kroenecke and Schindler (2010). Dechant *et al.* (2010) and Dechant and Finkenzeller (2013) were the first to employ downside risk portfolio optimizations with a set of direct and listed infrastructure assets. We follow Hamelink *et al.* (1997) and Maurer and Sebastian (2002) who investigate the inflation protection ability of several real estate investments vehicles by calculating the shortfall probability of a negative real return, assuming various different investment periods. The shortfall probability ($SP$) of each investment can be calculated by:

$$SP = Prob[r_0(k) < z_0(k)] \tag{10}$$

where $r_0(k)$ denotes the cumulative continuous compounded (multi-year) real return for an investment starting in t = 0 for a period of $k$ years. Since we are interested in inflation protection ability, the target real return $z_0(k) = 0$. Given that the $SP$ only indicates the frequency of a shortfall, we additionally calculate the Mean Excess Loss ($MEL$) to determine the potential extent of a loss. The $MEL$ therefore infers the average loss under the condition of a shortfall below the target return. The second risk metric is given by:

$$MEL = E[z_0(k) - r_0(k) | r_0(k) < z_0(k)] \tag{11}$$

Ultimately, we calculate the shortfall expectation ($SE$) in order to indicate the unconditional average loss. The $SE$ is the sum of losses weighted by their probabilities and hence determined by the product of the shortfall probability and the mean expected loss:

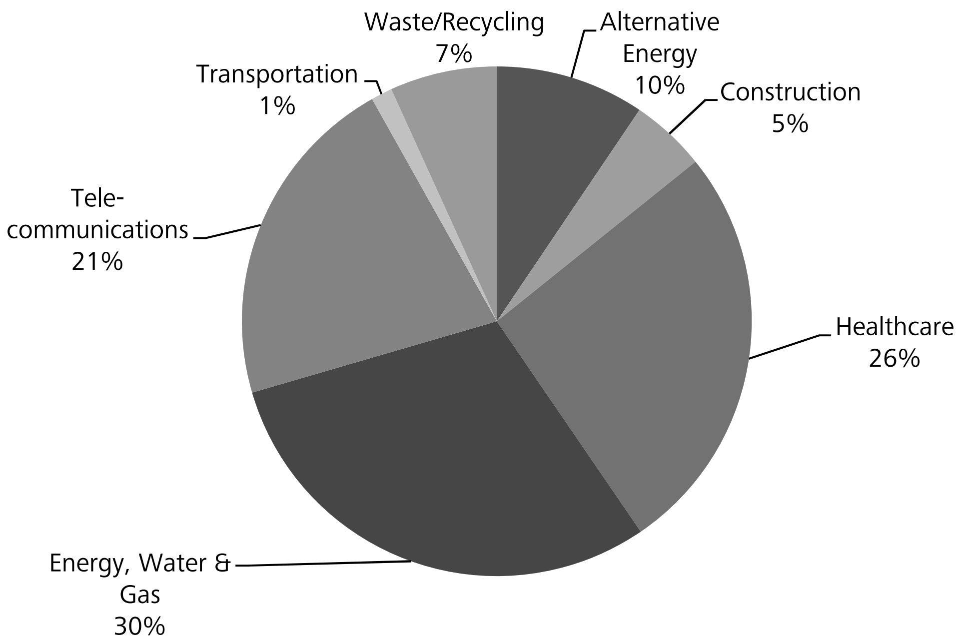
$$SE = E[\max(z_0(k) - r_0(k), 0)] = SP \cdot MEL \tag{12}$$

In this paper, we compare the inflation protection characteristics of direct and listed real estate and infrastructure investments for different (overlapping) holding periods of one year up to twenty-two years. This is conducted by analyzing a buy-and-hold lump sum investment with the assumption of full reinvestment, using historical return data. Thus, it is possible to examine how many years are necessary to achieve a positive real return and compare this across the different investment opportunities. It is crucial that the full reinvestment assumption in the direct real estate and infrastructure indices be regarded with some caution. However, the benefits of gaining deeper insights, especially into direct infrastructure performance, overweigh these limitations. Moreover, investments in direct vehicles are very cost-intensive, especially for infrastructure investments. This is mainly due to low levels of information efficiency, which result in high due diligence costs. Hence, transaction costs have to be considered in the calculations to allow for a meaningful comparison. Therefore, we include 6% purchase transaction costs for direct real estate and 7,5% purchase transaction costs for direct infrastructure investments, as proposed by Dechant and Finkenzeller (2013).

## 2.5 DATA

In this section, we present the data used for the empirical analysis. The dataset consists of quarterly U.S. total return indices, covering the period from Q1 1991 to Q1 2013 for direct and listed infrastructure and real estate investments. Listed infrastructure is represented by the UBS US Infrastructure & Utilities index, which consists of 75 infrastructure and utility companies listed in the U.S. This index has been used mainly in empirical studies on infrastructure investments (Newell and Peng, 2008; Bird *et al*., 2014). In order to reflect the listed real estate market in the U.S., we retrieve the FTSE EPRA/NAREIT index from Thomson Reuters Datastream. The direct real estate performance index is provided by the National Council of Real Estate Fiduciaries (NCREIF). The NCREIF TBI (NTBI) index reflects transaction-based performance and is therefore not subject to lagging and smoothing effects. The index is based on the TBI Index, which was formerly published by the MIT Center for Real Estate. In 2011, NCREIF took over the production and publication of the NTBI, with a slightly modified methodology compared to the MIT TBI.

**Figure 1: Direct Infrastructure Index Sector Breakdown**




Direct infrastructure performance is reflected by the CepreX U.S. Infrastructure Index provided by the Center of Private Equity Research (CEPRES), which was firstly used by Dechant and Finkenzeller (2013) in an asset allocation context. The index is a sub-index of the general private equity data base of CEPRES, which was already the source for several empirical studies including Franzoni *et al.* (2012) and Fuess and Schweizer (2012). The latter use a venture-capital sub-index of CEPRES for a research objective relatively similar to ours. The performance index is transaction-based and consists of 921 direct private equity investments in portfolio companies in infrastructure segments as represented in Figure 1, with a total capitalization of $28.9 billion of invested capital. The index methodology follows the S&P Case-Shiller methodology and is based on previous research on the index construction for illiquid assets by Peng (2001). The essence of the index methodology is straightforward: a single deal's overall performance (measured as the IRR based on actual cash flows) at the exit date is subdivided (according to precise cash flow statements during the holding period) over its entire holding period. Finally, the performance-index is an aggregation of all portfolio company performances, where each deal contributes to the index during its specific investment period. A more technical illustration of the index construction can be found in Schmidt and Ott (2006). Furthermore, the index is corrected for gearing, so as to represent unbiased direct infrastructure performance. All included sectors are in accordance with the definition of infrastructure from Wagenvoort *et al.* (2010) and Weber and Alfen (2010). The proportion of energy, healthcare and telecommunications assets is in line with the target allocation of various institutional infrastructure investors (Probitas Partners, 2012). In total, the index covers a 74% share of economic (transport, telecommunications, energy, alternative energy, waste/recycling, construction) and 26% share of social (healthcare) infrastructure assets.[2] Due to a sufficient number of transactions, together with a high market capitalization, this index represents an appropriate benchmark of direct infrastructure performance in the U.S.

The seasonally-adjusted Consumer Price Index (CPI), provided by the U.S. Bureau of Labour statistics, is used in the calculations as the measure of actual inflation. The actual inflation rate is then decomposed into expected and unexpected inflation. Several estimators of expected inflation were tested for their effectiveness as a proxy, using the following OLS model:

$$\Delta_t = \alpha + \beta E(\Delta_t) + \varepsilon_t \tag{13}$$

According to Stevenson (2000), the best proxy is chosen on the basis of two criteria. First, the intercept is not significantly different from zero and second, the beta coefficient is close to unity and therefore statistically significantly different from zero. We test the proxies as used by Le Moigne and Viveiros (2008) (i.e. lagged inflation, average inflation, 3M T-bills, 3M T-bills less time-varying real interest rates), Fama and Gibbons (1984) and two ARIMA models (ARIMA(0,1,1) and ARIMA(1,1,2)). Furthermore, we test two publicly available estimators of expected inflation provided by the Federal Reserve Bank (FED) of Cleveland and the FED of Philadelphia. Whereas the latter is a survey-based professional forecast, the inflation forecast of the FED of Cleveland is based on a model that combines information from different sources to overcome the shortcomings of other proxies. [3] The only proxy satisfying these criteria (intercept: 0.000513 not statistically significantly different from zero; beta coefficient: 0.88 statistically significantly different from zero at 1%) proved to be the data provided by the FED of Cleveland and is hence chosen for further calculations in this paper. In addition, the choice of this proxy constitutes a realistic assumption as it is publicly available to any potential investor.

**Table 1: Descriptive Statistics of Nominal Asset Returns and Inflation Measures**

| *Variable* | *Mean* | *Median* | *Max.* | *Min.* | *Std. Dev.* | *Skewness* | *Kurtosis* |
|---|---|---|---|---|---|---|---|
| Direct Infrastructure | 2.03% | 2.01% | 5.89% | -2.92% | 1.27% | -0.06 | 6.72 |
| Listed Infrastructure | 2.17% | 3.90% | 26.22% | -22.54% | 8.14% | -0.60 | 4.24 |
| Direct Real Estate | 2.06% | 1.77% | 16.67% | -17.57% | 6.01% | -0.74 | 4.91 |
| Listed Real Estate | 3.43% | 4.51% | 31.49% | -53.73% | 10.92% | -1.73 | 11.23 |
| Actual Inflation | 0.62% | 0.71% | 1.54% | -2.29% | 0.47% | -2.86 | 18.11 |
| Expected Inflation | 0.65% | 0.68% | 1.01% | 0.13% | 0.17% | -0.53 | 2.74 |
| Unexpected Inflation | -0.03% | -0.04% | 0.81% | -2.71% | 0.45% | -2.35 | 16.13 |
| Observations | 89 | 89 | 89 | 89 | 89 | 89 | 89 |

The descriptive statistics of the nominal quarterly returns of all series and the respective inflation rates are presented in Table 1. Infrastructure investments and direct real estate investments yield relatively comparable performance in terms of the mean quarterly nominal return. However, comparing the standard deviations, direct infrastructure exhibits the lowest risk, emphasizing its supposedly defensive investment characteristics and stable returns. Listed real estate, in contrast, exhibits the highest volatility and mean return in the sample period, which is not surprising, as the recent financial crisis is also included in the data. This fact is even more obvious when considering the minimum and maximum returns (-54% up to +31% nominal return). Interestingly, listed infrastructure and direct real estate yield relatively comparable risk-return characteristics. All assets have undoubtedly provided inflation protection over the given time frame, since the average nominal returns exceed the average inflation rate. In general, actual inflation was relatively low during the sample period. The effectiveness of the expected inflation proxy is reflected in the low mean unexpected inflation rate. The total observations included in the calculations add up to 89 quarters.

We further test all variables for stationarity. Table 2 shows the results of ADF unit root tests using equation (3) with an automatically chosen maximal lag length of 11. For the first-differences model, we only include a constant, and drop the trend variable. It is evident that all series must be differenced once to reach stationarity, i.e. all series are I(1) and can hence be subject to co-integration tests. As unit root tests are sensitive to the chosen lag length, we use both Akaike (AIC) and Schwarz's Info Criteria (SIC) to detect the optimal lag length and find qualitatively similar results. Moreover, Philips-Perron unit roots tests are conducted to ensure the robustness. For reasons of brevity, we only report the results of the ADF tests using SIC. All variables are I(1), that is, the first differences or the returns are stationary and can be used in the OLS regression without yielding spurious results.

**Table 2: ADF Unit Root Tests**

| *Variable* | *Log Levels* | *Log First Differences* |
|---|---|---|
| Direct Infrastructure | -0.434247 | -5.123026*** |
| Listed Infrastructure | -2.863487 | -7.898315*** |
| Direct Real Estate | -2.286976 | -10.70933*** |
| Listed Real Estate | -2.811488 | -7.210027*** |
| Actual Inflation | -2.933385 | -7.746008*** |

Notes: ***,**,* denote statistical significance at the 1%, 5%, 10 % levels, the critical value at 1% is -4.0710; lag-length was based on Schwarz Info Criterion (SIC), max. lag-length 11.

## 2.6 Empirical Results

### 2.6.1 OLS Regression Model

The results reported in Table 3 show the short-term inflation-hedging ability of the four different investment opportunities with respect to expected, unexpected and actual inflation. The hedging ability is tested using Equations 1 and 2 for the 89 quarters of the period from Q1 1991 to Q1 2013. As can be observed in Panel A, all estimators of the four variables with respect to expected inflation show positive signs, indicating a positive hedge. However none is significant at any reliable significance level, except for direct infrastructure investments. Thus, only direct infrastructure investments seem to offer a positive hedge against expected inflation.

This result is in line with the economic intuition from an asset valuation perspective. Generally, the asset value is calculated from the discounted value of the expected future cash flows from the asset. When the cash flows are positively linked to inflation, higher inflation should result in higher income. On the other hand, higher inflation leads to higher discount rates (as the risk-free rate in the form of a nominal bond yield will increase), which in turn impacts negatively on the value of any asset. Hence, it is essential to determine which of these opposing effects compensates the other. If companies are able to pass on increases in input costs, e.g. due to high pricing power or low price elasticity, the income effect should overweigh and there is a positive co-movement. This is particularly the case for direct infrastructure investments, as described in the previous sections. Furthermore, it is not surprising that direct infrastructure investments do not hedge the unexpected component of inflation, as the adjustment mechanism might be distorted due to some practical risks (see Section 3). Therefore, we also expect only a partial hedging ability of direct infrastructure with regard to actual inflation.

**Table 3: Short-Term Inflation Hedge**

*Panel A: Fama Schwert Framework*

| | Direct Infrastructure | Listed Infrastructure | Direct Real Estate | Listed Real Estate |
|---|---|---|---|---|
| Intercept | 0.003 | 0.014 | 0.005 | 0.026 |
| | (0.71) | (0.43) | (0.19) | (0.85) |
| Expected Inflation | 2.588*** | 1.265 | 2.448 | 1.986 |
| | (3.54) | (0.25) | (0.64) | (0.43) |
| Unexpected Inflation | -0.043 | 2.763 | 1.061 | 2.096 |
| | (-0.15) | (1.42) | (0.61) | (1.17) |
| Observations | 89 | 89 | 89 | 89 |
| $R^2$ | 0.13 | 0.02 | 0.01 | 0.02 |

*Panel B: Actual Inflation*

| | Direct Infrastructure | Listed Infrastructure | Direct Real Estate | Listed Real Estate |
|---|---|---|---|---|
| Intercept | 0.019*** | 0.006 | 0.013 | 0.025* |
| | (14.03) | (0.40) | (1.23) | (1.94) |
| Actual Inflation | 0.275* | 2.582 | 1.229 | 2.083 |
| | (1.81) | (1.42) | (0.91) | (1.24) |
| Observations | 89 | 89 | 89 | 89 |
| $R^2$ | 0.01 | 0.02 | 0.01 | 0.02 |

Notes: *T*-statistics are in parentheses and, if required, adjusted for heteroskedasticity and serial correlation using Newey and West (1987) standard errors. Coefficients marked with ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

Likewise, none of the other assets yields a hedge against unexpected inflation. In general, the low observed $R^2$ indicate that expected and unexpected inflation cannot effectively explain the total variance of nominal asset returns. This is of minor concern regarding the aim of this paper, as we want to analyze the co-movement of nominal returns with inflation. In addition, we further examine the inflation protection characteristics to overcome these shortcomings. However, this opens up avenues for further research aimed at identifying the performance drivers of nominal returns, especially those of direct infrastructure investments.

To verify the robustness of our results, we also use a more conventional expected inflation, i.e. three-months T-bills. The results are presented in Appendix 1 and are qualitatively in line with our previous findings. We further test the inflation-hedging ability against actual inflation and also find similar results. The results are reported in Panel B of Table 3. Again, only direct infrastructure investments show a positive, statistically significant co-movement with inflation. As expected, the estimator of 0.275 indicates that direct infrastructure investments only act as a partial hedge against actual inflation, which is not surprising, as the results in Panel A show that direct infrastructure investments do not hedge the unexpected part of inflation. Moreover, the statistically significant and positive constant suggests a positive real rate of return for the given time frame. However, as the constant is invariant to shifts in inflation and direct infrastructure acts only as a partial hedge against inflation, no definite conclusions can be made based on these findings. The results of the inflation protection section will shed more light on this problem.

The partial hedge might stem from the fact that the direct infrastructure index constitutes a heterogeneous set of infrastructure assets which may vary in the degree of inflation protection. Colonial First State (2011) rate different infrastructure sectors regarding their hedging ability and find that the telecommunication sector is a less effective hedge than other sectors. As the direct index constitutes a decisive share of telecommunication assets, this fact could negatively influence the short-term hedging ability. Another reason might be the regulatory lag that could distort the immediate adjustment mechanism. Furthermore, not every infrastructure investment must necessarily be tied to the CPI; it is also likely that other inflation measurements are contractually agreed upon. As we do not have any information on transaction levels, we cannot rule out this possibility. Given that this paper is the first to empirically examine the direct infrastructure sector in the USA, the results cannot be compared to those of other studies. However, the results do contradict the findings of Bird *et al.* (2014), who find no sign of inflation-hedging for unlisted infrastructure funds in Australia. These deviating results may result from the nature of index construction, time frame, country under observation and inflation measure (TIPS). Moreover, the fact that only 43% of the assets reflected in the Australian unlisted infrastructure index are actually located in Australia, certainly also influences the hedging ability with respect to inflation in that country.

Concerning listed infrastructure investments, we cannot find any evidence of short-term inflation-hedging, which is in line with the findings of Rödel and Rothballer (2012). In contrast, these results again contradict those of Bird *et al*. (2014), which we attribute to the different data frequency (they use monthly returns), time horizon (1995-2009) and inflation measure (TIPS). We suggest that the poor inflation hedge refers rather to the fact that listed infrastructure companies exhibit high levels of gearing, which in turn might have led to the poor inflation hedge. This is particularly the case over the course of the recent financial crisis, which was not included in their calculations. The direct infrastructure index, on the other hand, is unlevered and hence not subject to distortion caused by the debt structure. The empirical results for the real estate assets suggest that there is no short-term inflation-hedging ability, which conforms to the broad majority of empirical literature. Among others, Park *et al.* (1990), Liu *et al*. (1997), Lu and So (2001), Maurer and Sebastian (2002), Adrangi *et al.* (2004) and more recently Obereiner and Kurzrock (2012) find no short-term inflation-hedging ability for securitized real estate assets. Likewise, several more recent studies provide evidence that direct investments in commercial real estate do not, or only poorly hedge inflation, such as Hoesli (1994), Hoesli *et al.* (1997), Stevenson and Murray (1999), Sing and Low (2000), Chu and Sing (2004), or only hedge during periods of high inflation (Le Moigne and Viveiros, 2008). As the period under examination (1991-2013) is characterized by relatively low inflation rates, this may explain the poor hedging effectiveness of direct real estate in the short-run. Le Moigne and Viveiros (2008) also point out that the massive influx of capital to the real estate markets might have lead to a temporarily disturbed relationship to inflation due to overpricing. In addition, it is likely that the capital return component of the total return is likewise distorted by the severe financial crisis in the last years of our sample period.

In general, the empirical results are in line with the most of the existing literature, thus showing that the applied model yields robust results. As a consequence, the (partial) short-term inflation-hedging effectiveness of direct infrastructure investments can be empirically proven for the first time. Given that the long-term effects might differ, we test the long-run relationship between asset returns and inflation using Engle Granger co-integration tests in the next section.

### 2.6.2 Co-Integration and Granger Causality Tests

In this section, we present the results for the co-integration and Granger causality tests. Table 4 shows the output for the two-step Engle Granger co-integration tests, as well as the critical values from MacKinnon (2010). We perform ADF unit root tests using equation (5) with an automatically chosen maximal lag length of 11. The optimal lag length is chosen with both AIC and SIC, and yields qualitatively similar results. For reasons of brevity, we only present the results based on SIC. As can be seen, all critical values for the four different investment opportunities exceed the critical values at the 5% or 1% confidence intervals, thus indicating that all series are co-integrated. Hence, all return series share a statistically significant long-term relationship with the inflation series. This supports the hypothesis that real estate, as well as infrastructure investments, constitute a long-term hedge against inflation in the period from 1991 to 2013. This result further confirms the initial statement in the descriptive section that all series offered inflation protection in the given time frame, as the average nominal asset returns exceeded the average inflation rate.

The results for listed real estate coincide with the empirical evidence in the real estate literature. For instance, Chatrath and Liang (1998) and Ganesan and Chiang (1998), Hoesli *et al.* (2008), and more recently Obereiner and Kurzrock (2012), find evidence of a long-term relationship between listed real estate and inflation. This is further supported by Lee and Lee (2012), who also find a long-run relationship between inflation and developed real estate stock markets, whereas the relationship does not hold for emerging markets (see also Lee *et al.*, 2011). On the other hand, the real estate literature also contains several studies that support the long-run relationship between direct real estate and inflation, such as Barkham and Ward (1996), Matysiak *et al.* (1996), Chaudhry *et al.* (1999), Le Moigne and Viveiros (2008), Hoesli *et al.* (2008) and Park and Bang (2012).

**Table 4: Engle Granger Co-Integration Tests**

| *Variable* | *F-statistic* | *Critical Values* | |
|---|---|---|---|
| Direct Infrastructure | -2.099** | Critical Values | |
| Listed Infrastructure | -2.450** | 1% | -2.591 |
| Direct Real Estate | -2.834*** | 5% | -1.944 |
| Listed Real Estate | -2.732*** | 10% | -1.614 |

Notes: ***,**,* denote statistical significance at the 1%, 5%, 10 % levels, critical values according to MacKinnon (2010); lag-length was based on Schwarz Info Criterion (SIC), max. lag-length 11.

As for infrastructure investments, no study so far has investigated long-term inflation-hedging attributes. This is the first paper to fill the research gap and we are able to detect a long-term relationship between listed and direct infrastructure investments with inflation in the U.S. in the years from 1991 to 2013, thus implying a long-term inflation hedge. This supports the initial hypothesis that infrastructure investments and inflation share a strong relationship, due to the specific investment characteristics of infrastructure assets.

Next, we perform Granger causality tests as described in equations (8) and (9), including an error correction term, as the co-integration tests suggest that all series are co-integrated with inflation. The optimal lag length was set at two lags for all variables and based on AIC and SIC. The results for the short-run causality are shown in Table 5. The results indicate that both infrastructure and real estate investments display unidirectional Granger causality with inflation. Interestingly, the causality is reversed for the infrastructure and real estate assets, meaning that real estate returns are Granger-caused by inflation, whereas infrastructure returns seem to Granger-cause inflation. This result further confirms that infrastructure and real estate indeed represent two distinct asset classes.

Our findings are supported by prior research on direct and listed real estate, such as Barkham and Ward (1996), Stevenson (2000), Chu and Sing (2004) or Obereiner and Kurzrock (2012), who find that real estate returns are Granger-caused by inflation. However, there are also studies that find an opposing unidirectional causality or bidirectional causality between real estate returns and inflation, e.g. Tarbert (1996), Stevenson and Murray (1999), Stevenson (2000) and Le Moigne and Viveiros (2008). The latter point out that this might be due to the fact that real estate amounts to a small component of the CPI, which we believe should be particularly the case for housing (as in Stevenson, 2000). We adopt this argumentation to explain the unidirectional causality from infrastructure returns to inflation. As infrastructure companies, especially in the energy sector, generate their earnings from goods that are essential for the community, it is not surprising that there is causality from infrastructure to inflation. This interpretation is further backed by the fact that about 80% of the CPI components refer to the energy sector (Martin, 2010), which in turn comprises a decisive share in both examined infrastructure indices. As far as real estate is concerned, it is intuitive that inflation rather leads real estate than the other way around. Rents are not necessarily reviewed frequently (Hoesli *et al.,* 1997), hence leading to a lagged reaction of real estate to inflation changes.

**Table 5: Granger Causality Tests**

| *Null hypothesis* | *F-statistic* | *Probability* |
|---|---|---|
| Direct Infrastructure does not Granger-cause Inflation | 2.686* | 0.074 |
| Inflation does not Granger-cause Direct Infrastructure | 0.315 | 0.731 |
| Listed Infrastructure does not Granger-cause Inflation | 6.801*** | 0.002 |
| Inflation does not Granger-cause Listed Infrastructure | 0.896 | 0.896 |
| Direct Real Estate does not Granger-cause Inflation | 0.288 | 0.750 |
| Inflation does not Granger-cause Direct Real Estate | 3.218** | 0.045 |
| Listed Real Estate does not Granger-cause Inflation | 1.148 | 0.322 |
| Inflation does not Granger-cause Listed Real Estate | 4.634** | 0.012 |

Notes: ***,**,* denote statistical significance at the 1%, 5%, 10 % levels; lag-length was set on two based on Schwarz Info Criterion (SIC).

We further analyzed the estimated values of the respective error correction terms (E) of equations (8) and (9) to how the variables react and correct to the disparity between the long-run equilibrium level of inflation and the different asset returns. The findings support the prior results that inflation Granger-causes real estate and infrastructure Granger-causes inflation since the respective ECTs are negative and significant (e.g. -0.024 for direct infrastructure and -0.092 for direct real estate). This suggests that there are long-term adjustment effects and the real estate market reacts to changes in inflation, whereas inflation reacts to changes in the infrastructure market. Nevertheless, the magnitudes of the error correction terms are small, especially for direct infrastructure investments, thus only implying a gradually adjustment.

### 2.6.3 Inflation Protection

This section closes with the empirical results for the inflation protection characteristics of the four different asset returns. Table 6 summarizes different risk measures as described in equations (11) – (13) for investment periods of 1, 2, 3, … up to 22 years. In total, we investigate a period of 22 years from 1991-2012, i.e. we drop the first quarter return in 2013 to investigate only full-year returns. Thus, we are able to calculate 22 (non-overlapping) annual returns, 21 (overlapping) two-year returns and so on, and ultimately, one 22-year return. The respective average cumulative returns for each holding period are presented in the first row for each investment opportunity. The Shortfall Probability ($SP$) in row 2 indicates the number of periods in which no positive real return could have been achieved, i.e. no inflation protection could be assured. Accordingly, the mean expected loss ($MEL$) indicates the extent of loss in periods with a negative cumulative real rate of return and the shortfall expectation ($SE$) indicates the extent of loss, taking into account all periods.

**Table 6: Inflation Protection**

| *Investment Period in Years* | | **1** | **2** | **3** | **4** | **5** | **10** | **15** | **22** |
|---|---|---|---|---|---|---|---|---|---|
| Direct Infrastructure | Return | -1.84% | 3.84% | 9.77% | 15.71% | 21.64% | 50.13% | 79.85% | 117.04% |
| | SP | 77.27% | 14.29% | 5.00% | - | - | - | - | - |
| | MEL | 2.61% | 2.70% | 0.67% | - | - | - | - | - |
| | SE | 2.02% | 0.39% | 0.03% | - | - | - | - | - |
| Listed Infrastructure | Return | 5.75% | 10.93% | 15.61% | 19.93% | 24.79% | 47.37% | 77.00% | 126.51% |
| | SP | 22.73% | 28.57% | 35.00% | 26.32% | 16.67% | 7.69% | | - |
| | MEL | 26.05% | 22.26% | 15.97% | 14.45% | 18.57% | 0.97% | - | - |
| | SE | 5.92% | 6.36% | 5.59% | 3.80% | 3.09% | 0.07% | - | - |
| Direct Real Estate | Return | -0.29% | 6.11% | 13.43% | 20.48% | 28.92% | 70.76% | 110.60% | 119.57% |
| | SP | 45.45% | 23.81% | 20.00% | 21.05% | 16.67% | - | - | - |
| | MEL | 8.78% | 20.28% | 20.78% | 14.83% | 8.93% | - | - | - |
| | SE | 3.99% | 4.83% | 4.16% | 3.12% | 1.49% | - | - | - |
| Listed Real Estate | Return | 10.99% | 20.44% | 29.61% | 37.65% | 44.34% | 96.09% | 138.37% | 241.80% |
| | SP | 22.73% | 19.05% | 25.00% | 15.79% | 16.67% | - | - | - |
| | MEL | 22.42% | 34.47% | 23.54% | 30.52% | 17.79% | - | - | - |
| | SE | 5.10% | 6.57% | 5.88% | 4.82% | 2.97% | - | - | - |

Notes: Return = Average cumulative Return, SP = Shortfall Probability, MEL = Mean Expected Loss, SE = Shortfall Expectation.

Firstly, the average cumulative returns suggest that long-term investments in direct infrastructure would have a real value of 3.22$ (1$ * exp (1.1704)) by the end of 2012. Listed infrastructure and direct real estate would have achieved a quite similar outcome after 22 years of 3.54$ or 3.31$

respectively. In contrast, listed real estate investments would increase the real value by a factor of 11.22 which is attributable to the exceptionally good performance before the financial crisis and the recovery phase in the last few years of observation. During these years, listed real estate investments achieved distinctly higher returns than other asset classes under examination in this paper. However, this fact does not necessarily mean that listed real estate offered the best inflation protection in the years 1991-2012, as described later. Moreover, the negative effect of purchase transaction costs for the direct investment opportunities can be observed, as both assets exhibit a negative real return for one-year periods.

In general, the $SP$ decreases when the investment horizon increases, which reflects the familiar time diversification effect, i.e. less negative real returns are observable with longer holding periods. Most striking, it is evident that direct infrastructure investments constitute the best investment alternative, as a positive real return is already ensured after four years of investment. This reflects the descriptive statistics and fortifies the findings in the short-term inflation hedge section that direct infrastructure seems to offer stable real returns. In contrast, the $SP$ for real estate and listed infrastructure investments is 16.67% for an investment period of five years. Furthermore, listed infrastructure investments did not ensure a positive real return in one of the thirteen (7.69%) overlapping ten-year investment periods investigated, when both severe financial crises (2000 & 2008/2009) are included in the calculations. Unlike real estate investments, listed infrastructure investments did not perform exceptionally in the years before 2008 and hence could not compensate for the losses accordingly. Moreover, we include performance data following the severe financial crisis and find comparably poor performance for listed infrastructure investments. This result is particularly interesting, as it contradicts the general belief and claims from (industrial) research papers that listed infrastructure outperforms other asset classes (e.g. RREEF, 2008; Peng and Newell, 2007) in terms of risk-adjusted performance. Hence, listed infrastructure outperformance seems to be inconstant over time and influenced decisively by credit dislocation in the aftermath of the financial crisis 2008/2009 (Blanc-Brude, 2013).

The extent of loss, as indicated by MEL, differs decisively across the investments. In the event of a shortfall, only a minor share of the invested capital is lost, as far as direct infrastructure investments are concerned. Furthermore, direct real estate investments yield the second lowest $MEL$ for most of the different investment periods. As expected, the very volatile listed assets cause the highest losses in the case of a shortfall. Comparing listed infrastructure and real estate, it is evident that the $MEL$ of listed real estate substantially exceeds the $MEL$ of listed infrastructure investments (e.g. 31% vs. 15% for four-year investment periods). Hence, it is clear that listed real estate is not the best inflation protection, as might be assumed on the basis of the highest average cumulative returns. Although the probability of a shortfall of listed real estate vehicles is relatively similar to the other assets (expect direct infrastructure), the extent of loss is substantially higher. These findings also hold when the $SE$ is taken into account, but the deviations are less obvious. Ultimately, it can be concluded that direct infrastructure investments display the most desirable inflation protection characteristics when comparing all risk measures across the different investment opportunities.

## 2.7 Conclusion

Infrastructure, as well as real estate assets, are generally regarded as providing a good hedge against inflation, given their specific investment characteristics. While the linkage between real estate and inflation has been researched extensively in the past, there is still a lack of empirical evidence on infrastructure investments, in particular on direct infrastructure. By means of a unique dataset, this is the first paper to assess the inflation-hedging and protection characteristics of direct infrastructure. Specifically, we examine the short-term and long-term inflation-hedging ability of direct and listed real estate and infrastructure investments by using the Fama and Schwert (1977) methodology and Engle and Granger (1987) co-integration tests for the U.S. in the period from 1991-2013. Granger causality tests yield further insights into the short-run dynamics between real estate, infrastructure and inflation. Moreover, we take a closer look at the ability of both asset classes to achieve a positive real return after different investment periods, i.e. their inflation protection. Accordingly, on the one hand, we contribute to the literature by updating and reviewing the inflation-hedging ability of real estate. On the other hand and more importantly, this paper fills the research gap on the short-run and long-run relationship between (direct) infrastructure returns and inflation.

The results suggest that only direct infrastructure investments offer a partial hedge against expected inflation and actual inflation. None of the other assets shows a statistically significant co-movement with inflation in the short-run. In contrast, the results of the co-integration tests provide evidence that real estate, as well as infrastructure investments, are co-integrated with inflation, which indicates that both asset classes provide a long-term hedge against inflation. The causality tests underline these results, as there seems to be a unidirectional, but reverse causality between both asset classes and inflation – whereas inflation leads to real estate returns, inflation is caused by infrastructure returns. This result confirms the fact that real estate and infrastructure indeed represent two distinct asset classes. In addition, the different shortfall risk measures for assessing the inflation protection ability reveal that direct infrastructure investments exhibit the lowest downside-risk, compared to the other asset classes, followed by direct real estate investments. As expected, the listed vehicles are more volatile and therefore yield poorer inflation protection than direct investments.

The practical implications are straightforward. Investors seeking assets that are sensitive to inflation and mitigate inflation risk should consider direct infrastructure investments in their asset allocation strategy. This result extends the empirical findings that direct infrastructure investments should be included in investor’s portfolios in order to enhance diversification. Moreover, both real estate and infrastructure assets are able to hedge inflation in the long-run, which is particularly of interest for investors with a long-term investment horizon. As the causality tests reveal, a viable strategy might be to invest in infrastructure assets in order to assess inflation risk, as they are a factor producing inflation. Ultimately, direct infrastructure and real estate investments deliver stable (real) returns that ensure purchasing power after only a few years of investment. Moreover, the extent of loss is the lowest for direct infrastructure returns over the whole sample period. This holds despite several market downturns in the last twenty years of observation, emphasizing its potential role as a portfolio stabilizer for investors.

Nonetheless, some limitations have to be addressed. First of all, the results are based on a composite infrastructure index, as no sub-sector indices have been available so far. Since the hedging ability might differ by different infrastructure sub-sectors, further research should focus on sector specifics as soon as more data is available. Moreover, generally accepted and efficient benchmarks for direct infrastructure investment have to be established in the future. The index used in this paper thereby represents a first and meaningful step towards it. Concerning the results, the low $R^2$ in the OLS-regression indicate that inflation can barely explain the total variance of nominal returns. This opens up some avenues for further research, with respect to investigating the main performance drivers or macroeconomic variables influencing direct infrastructure returns both in the short- and long-run. However, more data is needed to assess these research questions in sufficient detail and with sufficient accuracy and reliability.

## 2.8 ENDNOTES

[1] Defining infrastructure investments correctly and consistently is crucial in practice, as the implicit and explicit definitions vary widely. For a recent overview of definitions, see Inderst (2013). For a brief distinction comparing real estate and infrastructure assets, see Dechant *et al.* (2010). An overall and compact literature review on infrastructure investments can be found in Oyedele *et al.* (2014).

[2] Depending on the definition of social infrastructure, waste/recycling may also be regarded as social infrastructure.

[3] For details, see Haubrich et al. (2012).

## 2.9 APPENDIX

### Appendix 1: Short-Term Inflation Hedge – Robustness Check

*Panel A: Fama Schwert Framework (Expected Inflation = 3M T-Bills)*

| | Direct Infrastructure | Listed Infrastructure | Direct Real Estate | Listed Real Estate |
|---|---|---|---|---|
| Intercept | 0.013*** | -0.007 | 0.005 | 0.028 |
| | (10.84) | (0.02) | (0.02) | (0.02) |
| Expected Inflation | 0.985*** | 4.147 | 2.257 | 1.812 |
| | (5.63) | (2.35) | (2.11) | (2.33) |
| Unexpected Inflation | 0.070 | 2.129 | 0.932 | 2.161 |
| | (0.57) | (0.34) | (1.85) | (1.97) |
| Observations | 89 | 89 | 89 | 89 |
| $R^2$ | 0.14 | 0.04 | 0.02 | 0.02 |

Notes: *T*-statistics are in parentheses and, if required, adjusted for heteroskedasticity and serial correlation using Newey and West (1987) standard errors. Coefficients marked with ***, ** and * denote statistical significance at the 1%, 5% and 10% levels.

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# 3 SOLVENCY II AND PORTFOLIO EFFICIENCY – THE CASE OF REAL ESTATE AND INFRASTRUCTURE INVESTMENTS

**Abstract**

We examine the potential effects of Solvency II on general portfolio efficiency, and specifically on the allocation of alternative assets by European insurers. The paper starts with a brief introduction to the Solvency II Directive, focusing on the rules for calculating the Solvency capital requirements (SCR), according to the standard formula. The following empirical analysis entails several portfolio optimizations considering six relevant asset classes for the time period from 1993-2013. We derive optimal portfolios with respect to portfolio risk and capital requirements, and finally combine both optimization problems. Our results suggest that, although the capital charges for real estate and infrastructure assets are not adequately calibrated, a significant shift of portfolio weights is not expected for the majority of European insurers. However, after Solvency II comes into effect, undercapitalized insurers may often not be capable of holding risk-optimal allocations of alternative assets.

## 3.1 INTRODUCTION

The current structural low interest rate environment is forcing institutional investors to rethink their asset allocation strategies and increase their exposure alternative assets, such as real estate and infrastructure. This is particularly the case for life insurance companies, which come under pressure to reduce their investment in currently low-yielding government bonds, given the high interest rate guarantees associated with obligations from existing life insurance policies. In addition, insurers also aim for a broadly diversified portfolio structure, in order to minimize portfolio risk, thereby protecting shareholders as well as policyholders. Recent studies conclude that real estate and infrastructure assets are more complements than substitutes for each other and can therefore help to reduce overall portfolio risk (e.g. Oyedele *et al.*, 2014). Accordingly, insurer's appetite for real estate and infrastructure assets is growing steadily over the past years and higher target allocations are observed (Blackrock, 2013; Allianz, 2013).

However, the forthcoming Solvency II Directive could counteract this trend, since it introduces a risk-based regulatory standard for European insurance companies, in order to determine their Solvency capital requirements (SCR). After Solvency II comes into effect, insurance companies will be subject to higher capital requirements aimed at ensuring policyholder protection, even in the case of severe macroeconomic shocks. The SCR varies by asset class and can be determined using the Solvency II standard formula provided by the regulatory authority, the European Insurance and Occupational Pensions Authority (EIOPA). Concerning the calibration of the standard formula, there is a general belief that the regulator overstates certain risks, especially for illiquid assets such as infrastructure and real estate, which in turn results in unreasonably high capital requirements (IPD, 2013; GDV, 2013; Braun *et al.*, 2014). Depending on their individual capitalization, profitability and the general competitive dynamics, it may become necessary for insurers to minimize their SCR. One possible field of action would thus be to restructure the asset portfolio accordingly, most likely by decreasing exposure to illiquid (and capital intensive) assets. If the results of such an "SCR-optimal" portfolio optimization are not in accordance with those of the conventional (mean variance) optimal asset allocation, Solvency II may lead to inefficient capital allocation in practice. As a result, the portfolio risk would increase, which contradicts the original purpose of the regulation. Furthermore, since insurance companies represent the largest European institutional investors, with approximately €8.5 trillion of assets under management (Insurance Europe and Oliver Wyman, 2013), changes in their investment patterns might also have severe effects on the pricing and product range offered on the capital markets.

We therefore analyze whether the Solvency II standard formula could indeed cause the abovementioned incentive incompatibility with respect to the asset allocation process. Our focus lies primarily on the potential shift of real estate and infrastructure weights within a multi-asset portfolio. We firstly use the traditional Markowitz (1952) portfolio optimization technique, in order to derive efficient portfolios with respect to risk. In a second step, we replace the empirical covariance matrix with a synthetic covariance matrix imposed by the regulator and determine SCR-optimal portfolios, i.e. we minimize the capital requirements for a certain target rate of return. Afterwards, we compare the derived portfolio weights with the results from the first optimization and can hence observe whether the Solvency II standard formula could indeed theoretically affect portfolio selection. Thirdly, we combine both optimizations and derive optimal portfolios with respect to capital constraints, i.e. we introduce an exogenously given Solvency Capital Budget (SCB) representing the actual capitalization of an insurer. These results show the potential effect that is most likely to be observable in practice. The contribution of our paper is therefore manifold. This is the first study to analyze the role of direct European infrastructure investments in a mixed asset portfolio. In addition, to the best of our knowledge, no other study has yet examined the potential effect of Solvency II on portfolio efficiency and asset allocation, accounting for different levels of capital budget. Most studies focus solely on the calibration of the standard formula and disregard the portfolio effects. Lastly, this paper adds to the research stream in the real estate literature on the disparity between theoretically optimal real estate (infrastructure) allocations and the actual allocations observed in practice.

The paper is structured as follows. Section 2 introduces the most relevant information concerning the Solvency II Framework and the rules for calculating and aggregating the SCR, using the standard formula. We further present the relevant literature on Solvency II and the role of real estate and infrastructure within the mixed asset portfolio in Section 3. Section 4 presents the empirical data, as well as the standard formula calibration for the relevant asset classes. The methodology and results are outlined in Sections 5 and 6. Section 7 discusses the results and the practical implications. Finally, Section 8 concludes on the main findings.

## 3.2 Solvency II Framework and Market Risk Standard Formula

The Solvency II Directive represents the most striking project for insurance supervision within the European Union and is hence of great importance for the industry. The primary aim of Solvency II is to increase the protection of policyholders by reducing the probability of insurance companies becoming insolvent. Additionally, uniform supervisory and regulatory standards are introduced, in order to create a level playing field in the European single market. These goals will be achieved by defining capital and risk management requirements, as well as consistent reporting and disclosure standards to be applied by all insurance undertakings across all 28 EU Member States and in three Member States of the European Economic Area.

In the remainder of this paper, we focus on the most relevant information on the Solvency II Directive with respect to our research question. Without a loss of generality, we do not consider the extensive (legal) sources and rather present a comprehensive overview alongside with few simplifications. Therefore, we concentrate on the passages specifying the methodology for calculating the SCR. Generally, the SCR can be calculated either using the standard formula imposed by the regulator or by implementing an internal model, which is able to more adequately reflect the individual risk structure of the particular insurance company. The focus of this paper is accordingly on the implementation of the Solvency II standard formula, which serves as a reference point for all insurance companies. Particularly small and medium-sized insurers will most likely not be capable of developing an internal model.

The standard formula aims to quantify the risk profile of a typical European insurance company as a whole. Technically, the formula refers to basic actuarial principles and is calibrated according to historical data. Generally, the Solvency II standard model consists of separate risk modules, including market risk, counterparty default risk, life underwriting risk, non-life underwriting risk, health underwriting risk and intangible asset risk, with each module consisting of further sub-modules (EIOPA, 2012). All risk modules are aggregated using (preset) correlations, as it is not likely that all potential risks occur at the same time. With respect to our research focus, we limit our analysis to the market risk module which is of particular importance, as it depends directly on the insurer's asset allocation. In addition, according to the results of the fifth Quantitative Impact Study (QIS5) (EIOPA, 2011) and a study from Fitch Ratings (2011), the market risk module accounts for 70-80% of the total SCR, emphasizing its predominant role in determining the overall SCR.

The market risk module itself consists of seven sub-modules that have to be aggregated in order to calculate the overall SCR for market risk ($SCR_{mkt}$): interest rate risk, equity risk, property risk, spread risk, concentration risk, illiquidity risk and exchange rate risk. In line with previous empirical studies (e.g. Gatzert and Martin, 2012; Braun *et al.*, 2014), we limit our analysis to the most important sub-modules, i.e. interest rate risk, equity risk, property risk and spread risk, which account for approximately 80% of the overall market risk (CEIOPS, 2009). Generally, the SCR for each sub-module refers to the change in the basic own funds ($\Delta\, BOF$), that occurs due to a shock or stress in the financial markets (e.g. real estate crisis, shifts in the term structure of interest rates etc.), where $BOF$ is defined as the difference between the market values of assets and liabilities.

Without loss of generality, $BOF$ is assumed to equal the equity position on the balance sheet. All specifications presented in the section below are from the "Revised Technical Specifications for the valuation and Solvency Capital Requirements calculations" released by EIOPA (2012).

The interest rate risk ($Mkt_{int}$) accounts for the fact that both assets and liabilities react to changes in the term structure of interest rates or interest rate volatility. As assets and liabilities are typically not perfectly matched (duration matched), both upward and downward shocks to the yield curve might have a negative effect on the $BOF$. Hence, the capital requirement for interest rate risk depends on two possible states,

$$Mkt_{int}^{up} = \Delta\, BOF|_{up} \tag{1}$$

$$Mkt_{int}^{down} = \Delta\, BOF|_{down} \tag{2}$$

where $= \Delta\, BOF|_{up}$ and $= \Delta\, BOF|_{down}$ are the changes in the net asset value of assets minus liabilities, caused by an upward or downward change in the term structure. The altered term structures are calculated by multiplying the current interest rate for a given maturity ($r_t$) with predefined upward and downward stress factors ($s_t^{up}$ and $s_t^{down}$), which are specified by EIOPA (2012) and shown in Appendix 1:

$$r_t = (1 + s_t^{up}) \tag{3}$$

$$r_t = (1 + s_t^{down}) \tag{4}$$

In any case, the absolute change in interest rates should be at least 1%-point. In practice, the downward stress scenario is of greater importance, especially for life insurance companies. This is due to the typically higher duration of insurer's liabilities compared to assets, causing the market values of liabilities to rise more than those of assets. Moreover, the value of liabilities usually exceeds that of interest-rate-sensitive assets. Hence, only a downward shift of the yield curve would have a negative impact on the $BOF$. In general, nonetheless, depending on which (negative) effect on the $BOF$ overweighs, either the upward or downward stress scenario must be used for further calculations.

The equity risk sub-module refers to sudden changes in the market value of equities and its influence on the $BOF$. Generally, EIOPA (2012) distinguishes between two types of equities: "type 1" and "type 2" equities. While "type 1" equities include all those listed in regulated markets in countries of the EEA or OECD, "type 2" equities comprise all equities listed in countries that are not members of the EEA or OECD. Moreover, all non-listed equity investments such as private equity, hedge funds, commodities and alternative investments (e.g. infrastructure investments) are also labeled as "type 2" equities. As a result, the capital requirement calculations for equity risk have to be carried out in two steps. First, the individual capital requirements ($Mkt_{eq,i}$) for each type of equity ($i$) are determined by the predefined stress factors:

$$Mkt_{eq,i} = \max(\Delta BOF | equity\ shock_i; 0) \tag{5}$$

where the stress factors for type 1 and type 2 equities add up to -39% and -49% respectively. These figures are based on historical total return data and refer to the value at risk (VaR) with a confidence level of 99.5% on a yearly basis. [1] Second, the resulting overall equity risk capital requirement is aggregated using a preset correlation matrix:

$$Mkt_{eq} = \sqrt{\sum_i \sum_j CorrIndex_{ij} * Mkt_{eq,i} * Mkt_{eq,j}} \tag{6}$$

where $CorrIndex_{ij}$ is the predefined correlation coefficient of 0.75 between "type 1" and "type 2" equities.

Likewise, the property risk sub-module accounts for risks arising from volatility in the real estate markets. This risk sub-module explicitly applies to direct investments (land, buildings and immovable property rights) and real estate fund investments, if it is possible to assess and evaluate the risks of the underlying assets (look-through approach). The capital requirement for property risk ($Mkt_{prop}$) is again determined by the 99.5% VaR on historical total return data and adds to -25%:

$$Mkt_{prop} = \max\,(\Delta BOF | property\ shock; 0) \tag{7}$$

Ultimately, the spread risk sub-module captures all risks that may occur due to changes in the level or in the volatility of credit spreads over the risk-free interest rate term structure. In particular, it comprises traditional fixed-income products (e.g. corporate bonds), asset-backed securities and other structured credit products, as well as credit derivatives. Depending on the type of product, the individual spread shock on bonds is determined as follows:

$$spread\ shock\ on\ bonds = \sum_i MV_i * F^{up}(rating_i) \tag{8}$$

where $MV_i$ is the market value of the credit risk exposure of bond $i$ and $F^{up}(rating_i)$ is a function of the individual credit quality and duration of each bond or loan. The actual factors can be derived using the table presented in Appendix 2. In this paper, we limit our analysis to the credit risk of corporate bonds, so that the capital requirement for credit spread ($Mkt_{spread}$) refers to the spread shock on corporate bonds as calculated with Equation (8) above.

$$Mkt_{spread} = max\ (\Delta BOF | spread\ shock\ on\ bonds; 0) \quad (9)$$

Finally, the total capital requirement ($SCR_{mkt}$) is an aggregation of all sub-risks using the pre-defined correlation matrix (the specific correlation figures are presented in Appendix 3) as follows:

$$SCR_{mkt} = \max\left\{\sqrt{\sum_i \sum_j CorrMkt_{ij}^{up} * Mkt_i^{up} * Mkt_j^{up}}\,;\ \sqrt{\sum_i \sum_j CorrMkt_{ij}^{down} * Mkt_i^{down} * Mkt_j^{down}}\right\} \quad (10)$$

with $i, j\ \in \{interest\ risk, equity\ risk, property\ risk, spread\ risk\}$ and "up" and "down", indicating whether the upward or downward stress scenario for interest rate risk is relevant. The correlation coefficients differ slightly depending on the "up" or "down"-scenario. The actual calibration of the standard model for our empirical analysis will be presented in Section 4 together with the descriptive statistics of the dataset.

## 3.3 Literature Review

### 3.3.1 Solvency II

A considerable body of literature has been published on Solvency II related issues. Many of these studies focus mainly on the inappropriateness of risk measures and the underlying covariance matrix in the Solvency II standard formula (e.g. Mittnik, 2011; Christiansen *et al.*, 2012; Gatzert and Martin, 2012) or conduct a qualitative analysis of the potential effects (e.g. Fitch, 2011; CFGS, 2011; Ernst & Young, 2011, 2012; Severinson and Yermo, 2012). Another research stream investigates the conjoint effects of the implementation of the new Basel III regulation for the bank sector and Solvency II (e.g. Kaserer, 2011; Al-Darwish *et al.*, 2011). In this section, we therefore focus only on the publications most relevant to our research question. We shed light on important industry and academic publications that concentrate on the implications for asset allocation and the investment policies of insurers.

Based on the results of the QIS4, Rudschuck *et al.* (2010) conclude that the new risk-based capital requirements will force insurers to reduce their equity investments (e.g. stocks). As a result, insurers will struggle to meet required returns in the current low-interest-rate environment. Van Bragt *et al.* (2010) analyze the impact of different investment policies on the capital requirements (according to QIS4) for a representative life insurer. They find that the investment policy, in terms of portfolio structure and asset duration, may impact decisively on the regulatory capital requirements. For instance, a decrease in real estate allocation yields smaller capital requirements for the insurer when the duration of total assets remains constant. However, when allowing the total asset duration to change, a similar capital requirement can also be obtained with an allocation of real estate in the portfolio. Therefore, no definite conclusions can be made, based on these results. In addition, the risk factor for property in QIS4 corresponds to the equity risk factor, since a separate property risk factor was not introduced until QIS5.

Using the results of QIS5, a study by Morgan Stanley and Oliver Wyman (2010) investigates the effects of Solvency II on four different virtual insurance companies and finds similar results concerning the potential investment policy. They expect a shift away from illiquid assets, such as real estate and private equity, especially for insurers with a low market-risk appetite. Nonetheless, companies may still hold such assets tactically, in order to maximize portfolio returns. They further hint at the fact that the capital requirements of rating agencies, such as Standard & Poors (S&P), will potentially still play an important role and may be the binding capital constraint for insurers. This view is supported by Hoering (2012), who compares the capital requirements of a representative European insurer, both under Solvency II standard formula and the S&P rating model. Accordingly, the S&P model requires 68% more capital than the standard model for a comparable level of confidence.

Fischer and Schlütter (2012) analyze the influence of the equity risk parameter calibration of the standard formula on the insurer's optimal investment strategy and capital structure. If the insurer's individual capitalization is considered as an endogenous variable, the authors interestingly find constellations in which a higher equity risk charge does not yield a significant reduction in insolvency risk. The insurer may not only react with a reduction of stock investments, but also reduce the overall capitalization accordingly. Recently, Braun *et al.* (2013) conduct portfolio optimizations including a broad range of assets accounting for capital charges according to the Solvency II standard formula and a partial internal model. As the standard formula focuses purely on the risk of individual assets, the influence of expected returns is neglected. Thus, efficient portfolios are not systematically preferred under the Solvency II standard formula. That is the insurer is regulatorily forced to hold more risky portfolios in order to achieve the desired target portfolio return, which contradicts the primarily aim of Solvency II. In contrast, a partial internal model may overcome these limitations and permit insurers to hold efficient portfolios in terms of desirable risk-and-return profiles. Ultimately, Braun *et al.* (2014) investigate the impact of private equity investments on the capital requirements of a representative life insurer under Solvency II and Swiss Solvency Test (SST). They conclude that Solvency II and SST heavily penalize private equity investments, whereas the implementation of an economically sound internal model can lower the capital requirements, hence enabling potential investments in alternative asset classes.

In summary, no empirical studies focus on the impact of Solvency II on real estate and infrastructure and the potential shift of weights within the insurer's portfolio. Investment Property Database (IPD) (2011, 2013) research reports offer a detailed review of the Solvency II regulatory framework with respect to the property shock factor calibration, which is based on the U.K. real estate market. They criticize the lack of comparability between the general European real estate market performance and the performance of the U.K. real estate market, particularly during the recent financial crisis. Based on newly available national and pan-European quarterly property indices, IPD finds no 0.5% tail value at risk exceeding -15% in markets besides the U.K.. Hence, the property shock factor of -25% does not seem appropriate for direct real estate investments. Therefore, IPD expects decisive impacts upon the real estate allocation of European insurers. However, it is not likely that the regulator will change the property risk factor, so that -25% SCR based on QIS5 will have to be applied.

Likewise, the literature contains no study on the potential impact of Solvency II on infrastructure allocations. This can be attributed mainly to the fact that infrastructure, as an emerging asset class, is not classified separately and no general accepted performance benchmark exists so far. As a consequence, the risk factors for private equity investments have to be applied in the standard formula, which may overestimate the potential risk associated with direct infrastructure investments, rendering it unattractive for insurance companies, despite its desirable risk-and-return characteristics. Hence, the German Insurance Association (GDV) recently released a proposal "for an appropriate solvency capital requirement for long-term investments in infrastructure or renewable energies" (GDV, 2013). They advocate a new sub-module "infrastructure risk", with a risk factor of -20% and zero correlation to equity risk, interest rate risk or any other market risk sub-module for selected direct infrastructure investments that meet a list of qualitative criteria (e.g. located in the OECD, regulated business, unlisted investments, low default risk etc.). All other infrastructure assets that do not meet these criteria should instead be subject to the property risk sub-module. However, the European Insurance and Occupational Pensions Authority (EIOPA) recently announced that the standard formula calibration will not be changed in the near future, since improved data is needed for a reliable reassessment of risk. A general overview of the treatment of different infrastructure investment vehicles under Solvency II and related issues can be found in Gatzert and Kosub (2014) and EIOPA (2013).

### 3.3.2 Real Estate and Infrastructure Allocation in Insurers' Portfolios

Concerning the role of alternative assets in the mixed-asset portfolio, the real estate literature already contains numerous studies on the optimal direct real estate allocation, using different optimization techniques. Recent studies conclude that the optimal weight of direct real estate investments in a mixed-asset portfolio should be about 15-30% (Ziobrowski and Ziobrowski, 1997; Chun *et al.,* 2000; Brounen and Eichholtz, 2003; Hoesli *et al.,* 2003, 2004; Bond *et al.,* 2006, Lee and Stevenson, 2006; Hoesli and Lizieri, 2007; Brounen *et al.,* 2010; Rehring, 2012). However, the theoretically optimal direct real estate allocation does not correspond with the allocation in practice of institutional investors, more precisely of insurance companies. According to a representative survey among German insurers, the allocation of direct real estate is only about 5.4% of total assets (Ernst & Young, 2014). Similarly, the average real estate allocation of European insures amounts to about 4% (Insurance Europe and Oliver Wyman, 2013), showing a remarkable disparity between theoretical and practical real estate asset allocations of insurers. This figure is supported further by the information provided in the QIS5 study in which 90% of all insurers affected by Solvency II took part. After adjusting the balance sheet for assets that are not capital investments, the percentage of direct real estate investments amounts to 4.8% of the total balance sheet (EIOPA, 2011).

The disparity between theoretical and actual real estate allocations formed the basis for further extensive research streams. Chun *et al.* (2000) were the first to show that institutional investors not only aim to construct efficient portfolios and minimize investment risk, they also aim to match their assets with their liabilities. This study was followed by several others (e.g. Craft, 2001; Booth 2002; Chun *et al.,*2004; Brounen *et al.,* 2010) using an asset-liability framework in order to investigate the optimal portfolio composition of institutional investors. The majority of these studies conclude that the optimal share of direct real estate with respect to an Asset Liability Management (ALM) is merely 6-16%. Another possible explanation refers to the investment characteristics of direct real estate that can only partly be reflected by performance indices such as high transaction costs and illiquidity (Hoesli and Lizieri, 2007). In this context, Bond *et al.* (2006) show that the real estate allocation estimated via mean-variance optimizations may decrease decisively, as soon as lengthy transaction periods are accounted for. More recently, Rehring (2012) examines the role of real estate in a mixed-asset portfolio and finds that transaction costs and the investment horizon predominantly affect the allocation of short- and medium- term real estate investors, thus revealing lower theoretical allocations.

By contrast, there are few empirical studies on the role of direct infrastructure investment in mixed assed portfolios, as most studies only consider the listed infrastructure universe, due to limited data availability. Finkenzeller *et al.* (2010) were among the first to investigate the role of unlisted infrastructure in a downside-risk framework, and find considerably high theoretical allocations in low to medium expected-return portfolios. However, when the expected return increases, theoretical allocations decrease to 3-20%. Using a professionally constructed US-transaction-based infrastructure index, Dechant and Finkenzeller (2013) examine the role of direct infrastructure in a dynamic asset allocation framework. Similar to the previous findings, they discover high optimal allocations of direct infrastructure up to approximately 30% in low- to medium risk portfolios. In addition, direct infrastructure may be particularly beneficial for investors with a long-term investment horizon.

Yet, the actual infrastructure allocations in the mixed-asset portfolios of institutional investors differ decisively from the theoretical allocations suggested by recent asset allocation studies. As shown in a recent survey of Mercer including 1,200 institutional investors in 13 European countries, the average infrastructure allocation adds to approximately 3% of the overall assets (Mercer, 2013). A joint study by the Steinbeis Research Center for Financial Services and Commerz Real reveals the average infrastructure allocation among German institutional investors to be around 1%. However, according to the study, insurance companies are the leading infrastructure investors with an average allocation of 2% (Steinbeis, 2012). According to Preqin, 173 insurance companies reporting to its database exhibit a mean current allocation to infrastructure of 1.9% which is in line with the abovementioned figures (Preqin, 2013). Hence, the actual infrastructure allocation of insurance companies is roughly 2% in practice. Nevertheless, the appetite of institutional investors for infrastructure investments is notable; several surveys provide evidence that investors aim to increase their infrastructure allocations (Blackrock, 2013; Preqin, 2013; Insurance Europe and Oliver Wyman, 2013; Tower Watson, 2013). This emphasizes the potential for the asset class to grow decisively in the future. Since real estate and infrastructure assets exhibit common features, such as illiquidity and high transaction costs, the discrepancy might also be well explained by the arguments stated for real estate investments. Nevertheless, no study has yet examined this issue empirically.

## 3.4 Data and Descriptive Statistics

### 3.4.1 Data Selection

In this section, we present the data set used in the empirical analysis, as well as the corresponding standard formula parameters. We aim at constructing a representative portfolio of a European insurer, by using common benchmark indices as a proxy for the respective asset class performance. That is, we assume each intra-asset class portfolio has already been optimized prior to the overall portfolio optimization. Our dataset consists of the following six asset classes: real estate, infrastructure, government bonds, corporate bonds, stocks and money market instruments. We use quarterly total return data over 21 years spanning the period from Q1 1993 to Q4 2013, i.e. our data sample contains 84 observations in total. [2] The 21-year horizon ensures a sufficiently long time frame, in order to cover several business cycles and the two severe economic downswings in the past two decades. All data, except for infrastructure, were obtained from Thomson Reuters Datastream.

Direct real estate performance is represented by the IPD U.K. Property Total Return Index which consists of approximately 3.500 directly held properties in the U.K. with a total capital value of 40.5 billion GBP (as of September 2014). Since the index is based on monthly valuations of the properties, the capital return component is subject to lagging and appraisal smoothing. Hence, we follow Rehring (2012) and correct the capital returns for these effects, using the approach of Barkham and Geltner (1994) with an unsmoothing parameter of 0.625. In addition, direct real estate investments entail high transaction costs for an investor, thus reducing the actual returns. Therefore, we further correct the total returns for roundtrip transaction costs of 7%, as proposed by Collet *et al.* (2003), Marcato and Key (2005) and Rehring (2012). [3]

Direct infrastructure performance is reflected by the CepreX Europe Infrastructure Index provided by the Center of Private Equity Research (CEPRES). A different regional sub-index was already used in an asset allocation context by Dechant and Finkenzeller (2013), as well as by Wurstbauer and Schaefers (2015). The infrastructure indices are sub-indices of the general private equity data base of CEPRES, which was the source for several empirical studies, including Franzoni *et al.* (2012) and Fuess and Schweizer (2012). The performance index is transaction-based and consists of 638 direct private equity investments in portfolio companies in infrastructure segments [4] across Europe with a total capitalization of €25.8 billion of invested capital. The index is corrected for gearing, transaction costs, carried interest and management fees so as to represent unbiased direct infrastructure performance. Thanks to a sufficient number of transactions, together with a high market capitalization, this index represents an appropriate benchmark of direct infrastructure performance in Europe.

To proxy the European government bond universe, we use the Citigroup European World Government Bond index with mixed maturities. The index covers 16 European countries and is frequently used by investment managers as a benchmark for the government bond markets. As there is no European-wide benchmark with a sufficiently long time series for corporate bonds, we employ the Barclays U.S. Corporate Bonds Market to represent corporate bonds in this study. [5] The index consists of different investment-grade bonds with different maturities, which is in line with the actual bond portfolios held by European insurance companies. The stock portfolio of insurers is represented by the total return index of the MSCI Europe Index, which covers 437 large and mid-cap stocks across 15 developed markets in Europe, thus representing approximately 85% of the total market capitalization in Europe. Lastly, short-term money market investments are represented by the JP Morgan Euro 1M Cash Total Return Index. The respective standard formula calibration resulting from the chosen data set is presented in the section below.

### 3.4.2 Input Data for SCR Calculations and Descriptive Statistics

We use the information provided in Section 2 to calculate the individual SCR, as well as the aggregate SCR, for the overall portfolio (i.e. $SCR_{mkt}$). As for direct real estate investments, a single SCR of -25% has to be applied. The equity risk sub-module must be calculated and aggregated separately for type 1 and type 2 equities, before deriving the overall market risk capital charges. While the MSCI Europe Index represents type 1 equities with a -39% SCR, the infrastructure time series is clustered as type 2 equity thus requiring a -49% SCR. The gross capital charges for both types of equities are aggregated, using the regulatory prescribed correlation of 0.75. Government bonds, as well as money market instruments, are not subject to capital charges and therefore do not enter the capital charge calculations directly. Nevertheless, the overall SCR also depends on the allocation of government bonds, as it influences the total duration of the portfolio and therefore the interest rate risk charges. The interest rate sensitivity of government bonds is given by the modified duration of the Citigroup European World Government Bond index (6.66 as of 31 December 2013). [6]

To calculate the capital requirements for the spread risk module, we use Formula 8 from Section 2. That is the respective duration and rating of the corporate bonds portfolio determines the actual SCR. We use the modified duration of the Barclays U.S. Corporate Bonds Market index as of 31st December 2013, which amounts to 6.79. Since the bond index represents a bucket of investment-grade fixed-income securities, we average the spread shocks across the credit quality steps 0 to 3 for the duration of 6.79, using the prescribed formulas from the Appendix 2. As a result, we obtain a single shock factor of -8.9% for the spread risk module.

Concerning the interest rate risk module, we use the simplified approach suggested by Hoering (2013), who determines the capital requirements based on the duration gap between assets and liabilities. The duration gap is calculated as the difference between the duration of the asset side and the duration of the liability side and hence indicates the interest rate sensitivity of the basic own funds ($BOF$) of the insurer. While the duration of the asset side is determined by the actual portfolio allocation, more precisely, the relative weights of the duration of government bonds and corporate bonds, the duration of the liability side is given exogenously. We use the information provided by the Fourth Quantitative Impact Study QIS4 (CEIOPS, 2008), according to which the median duration of liabilities of life insurers in Europe is approximately 8.9. Moreover, Braun *et al* .(2014) set the duration of a representative life insurance to 10.0, based on several practitioner studies for the German life insurance market. Hence, we use the average of both studies and define the duration of the liability side as 9.5 in this study.

Following Braun *et al.* (2014) and Hoering (2013), the interest rate shock is then approximated by a parallel upward and downward shift of the term structure of interest rates, i.e. we assume a flat interest rate curve. The unstressed interest rate is therefore given by the average of the AAA-rated euro area central government spot yield curve as of 31st December 2013, which amounts to 0.48%. Likewise, we average the prescribed shock factors from the Solvency II Directive for different maturities (cf. Appendix 1), which results in a single upward shock of +43% and a single downward shock of -37%. Given that the absolute change in the term structure should be at least 1 percentage point (cf. Chapter 2) and that the unstressed interest rate only amounts to 0.48%, these two shocks are not relevant, since the absolute change in the term structure would be less than 1 percentage point. Therefore, we assume interest rate changes of 1 percentage point for our calculations as prescribed by the regulator. In addition, the duration of liabilities exceeds the duration of assets for every possible portfolio composition, thus limiting the analysis to the downward scenario only, i.e. a change in the unstressed interest rate of -1 percentage point. Ultimately, the SCR for interest rate risk is calculated by multiplying the downward interest rate shock of -1 percentage point by the duration gap, which in turn is determined by the respective portfolio allocation. For example, a duration gap of 5.0 would require capital charges for the interest rate risk of -5%.

Table 1 summarizes the empirical risk and return characteristics, as well as the empirical and regulatory correlation matrices for the six asset classes. The upper figures in the first section of the table thus represent the empirical correlations, and the figures in parentheses below refer to the respective regulatory correlations as imposed by the regulator. Since government bonds and money market instruments are not subject to capital charges, some cells are left blank and we only present the empirical correlations. Likewise, the interest rate correlations are only relevant for the SCR calculations, so that no empirical correlations are presented. The second section of the table provides information on the mean quarterly returns, the respective standard deviations as well as the corresponding SCR, as already outlined in above sections. Ultimately, the durations of the bond investments are shown in the bottom row.

**Table 1: Descriptive Statistics and Solvency II Standard Formula Calibration**

| | Real Estate | Infrastructure | Government Bonds | Corporate Bonds | Stocks | Money Market | Interest |
|---|---|---|---|---|---|---|---|
| Real Estate | 1.00<br>(1.00) | | | | | | |
| Infrastructure | 0.14<br>(0.75) | 1.00<br>(1.00) | | | | | |
| Government Bonds | 0.03<br>- | 0.05<br>- | 1.0<br>- | | | | |
| Corporate Bonds | 0.19<br>(0.50) | -0.04<br>(0.75) | 0.52<br>- | 1.0<br>(1.0) | | | |
| Stocks | 0.47<br>(0.75) | 0.18<br>(0.75/1.00) | 0.06<br>- | 0.14<br>(0.75) | 1.00<br>(1.00) | | |
| Money Market | -0.13<br>- | 0.37<br>- | 0.29<br>- | 0.07<br>- | -0.02<br>- | 1.00<br>- | |
| Interest | -<br>(0.50) | -<br>(0.50) | -<br>- | -<br>(0.50) | -<br>(0.50) | -<br>- | -<br>(1.00) |
| Mean | 2.06% | 1.47% | 1.57% | 1.83% | 2.55% | 0.87% | |
| STD | 5.28% | 0.90% | 1.99% | 3.34% | 9.49% | 0.58% | |
| SCR | -25% | -49% | - | -8.9% | -39% | - | 1% × DG |
| Duration | - | - | 6.66 | 6.79 | - | - | |

Notes: The upper division of the table shows the empirical correlation and the regulatory correlation coefficients (in parentheses below). All correlations refer to the downward interest shock scenario. Stocks and infrastructure are aggregated first at a 0.75 correlation. The lower division of the table shows the mean quarterly returns of the assets and the corresponding standard deviations (STD). Moreover, the Solvency capital requirements (SCR) are presented. The interest rate risk SCR needs to be calculated, depending on the actual duration gap (DG). The respective durations for the assets are outlined in the bottom row.

The descriptive statistics clearly reflect the expected risk and return relationship for the assets in this study. Short-term money market instruments yield the lowest returns and also exhibit the lowest risk in terms of the standard deviation. At the other extreme are stock investments with mean quarterly returns of 2.55% and 9.49% standard deviation, thus representing the riskiest and best-performing asset. The mean return of infrastructure is smaller than those of real estate and government bonds, emphasizing its defensive investment characteristics. However, the SCR for the six asset classes do not adequately reflect the corresponding empirical risk measures. While infrastructure exhibits a very conservative risk and return relationship, it is subject to the highest SCR of all asset classes. One would expect stock returns to be subject to the highest capital requirements, due to the risk profile. Likewise, the SCR for real estate investments is overstated compared to corporate bonds. All in all, real estate and infrastructure assets seem to be penalized and seem therefore not attractive for insurers on a SCR-adjusted basis.

In order to evaluate the potential role of real estate and infrastructure within the mixed asset portfolio, it is necessary also to take into account the correlation matrices. It is evident that the regulatory correlations, for both infrastructure and real estate, are severely overestimated in comparison to the empirical correlations. For example, the empirical correlation coefficient between real estate and stocks amounts to 0.47, whereas the regulatory correlation coefficient is 0.75. As a result, the desirable diversification benefits offered by the relatively low empirical correlations might be eroded from a SCR perspective. The figures suggest rather that the properties of infrastructure and real estate as portfolio diversifiers could be lost. As no reliable conclusions can be based only on these figures, we perform several optimization setups in order to evaluate the potential impact of Solvency II on the actual allocation. In the next section, we present the methodology used in our empirical analysis.

## 3.5 METHODOLOGY

The first optimization problem serves as a reference point for the further analysis and is based on the standard Markowitz mean-variance framework with the empirical covariance matrix ($\sum_{emp}$). The objective and restrictions are as follows:

$$min_w: STD = \sqrt{w * ((\sigma_{STD})^T \times \boldsymbol{\Sigma}_{emp} \times \sigma_{STD}) * w^T} \tag{11}$$

subject to:

$$E(r) = \bar{r} * w^T \tag{12}$$

$$w_i \geq 0 \tag{13}$$

$$\boldsymbol{\Sigma}_i w_i = 1 \tag{14}$$

and

$$w_i \leq u_i \quad \text{i} \in \{1,2,\ldots,6\}. \tag{15}$$

The aim of the optimization is simply to minimize the portfolio risk with respect to all possible target returns (Equation 12). Equation (13) excludes short positions and Equation (14) serves as the budget constraint. To ensure that only realistic portfolio compositions are obtained, which do not conflict with existing investment regulations, we introduce different investment limits as upper boundaries ($u_i$) for the individual asset classes ($w_i$) in Equation 15. Given that these regulations vary across Europe and according to the relative importance of the German insurance market, the investment limits in the empirical study are inspired by the German "Regulation on the Investment of Restricted Assets of Insurance Undertakings" (Investment Regulation; German:

Anlageverordnung). Specifically, we restrict our analysis in the following manner: real estate weights are capped at 25%, infrastructure weights are capped at 5%, stocks are capped at 35% and infrastructure and stocks are not allowed to jointly exceed 35% of total assets. All other asset classes (government bonds, corporate bonds and money market) are not subject to any investment limits. Originally, corporate bonds would also be included in the joint 35% cap regulation with stocks and infrastructure. However, we abstain from introducing an investment limit to corporate bonds, due to their relative importance within the average European insurer's asset allocation. According to the European insurance and reinsurance federation, the average corporate bond allocation amounts to 35% of the overall portfolio (Insurance Europe and Oliver Wyman, 2013), which also reveals that such a regulation does not prevail across all jurisdictions. [7]

In a second step, the information provided by the regulator (cf. Chapter 2) is used and the empirical correlation matrix is replaced with the imposed correlation matrix of the regulator ($\sum_{reg}$). Likewise, the empirical risk measures for all asset classes are replaced with the SCR. In addition, the interest rate risk factor is now taken into account. This optimization problem can now be stated as follows:

$$min_w: SCR = \sqrt{w * ((\sigma_{SCR})^T \times \boldsymbol{\Sigma}_{reg} \times \sigma_{SCR}) * w^T} \tag{16}$$

subject to:

$$E(r) = \bar{r} * w^T \tag{17}$$

$$w_i \geq 0 \tag{18}$$

$$\boldsymbol{\Sigma}_i w_i = 1 \tag{19}$$

and

$$w_i \leq u_i \quad \mathrm{i} \in \{1,2,\dots,6\}. \tag{20}$$

Although this problem looks like the familiar quadratic optimization problem again, a variety of numerical issues are associated with changing the covariance matrix. First, the matrix imposed by the standard formula is not positive semi-definite. While this is not a problem for the simple aggregation of the overall SCR, it causes a discontinuity in the quadratic objective function, and hence leads to an overrun of the optimization algorithm. Therefore, we apply the algorithm of Higham (2002), in order to obtain the nearest positive semi-definite matrix. Second, both the equity risk SCR and the interest rate risk SCR are functions of the portfolio allocation itself. While the equity risk SCR accounts for diversification within the equity risk sub-module, the interest rate risk SCR is caused by the duration gap, which depends on the actual weights of corporate and government bonds. Consequently, the optimization problem itself alters, whenever the solution vector (i.e. portfolio weights) changes. This causes a circularity problem and again, discontinuity, within the optimization. Depending on the starting point of the optimization, the algorithm may therefore only find local minima. To overcome this issue, all *N* permissible combinations of infrastructure investments, stocks, corporate bonds and government bonds are enumerated up to the fourth decimal place. For any given target return, the original problem is now solved *N* times. Each of these *N* optimizations uses the corresponding preset asset weights as additional constraints (i.e. the weights of these four asset classes are fixed). Hence, the covariance matrix no longer exhibits circular references. Subsequently, only the remaining asset weights for money market and real estate are derived by the optimization. Finally, the portfolio allocation with the lowest SCR of all the *N* optimization results is chosen as the global optimum for the given target return.

Both optimization problems can be considered extreme points. No insurer will strictly adhere to only one of the optimization objectives (SCR *or* STD). Since any insurance company will not only face certain capital constraints, but also the need to manage the overall portfolio risk, it is rather the combination of both optimizations, which is of particular relevance. Therefore, we introduce a solvency capital budget (SCB) as an additional constraint into the original Markowitz optimization problem. The problem is now formulated as follows:

$$min_w : STD = \sqrt{w * ((\sigma_{STD})^T \times \boldsymbol{\Sigma}_{emp} \times \sigma_{STD}) * w^T} \tag{21}$$

subject to:

$$SCB \geq \sqrt{w * ((\sigma_{SCR})^T \times \boldsymbol{\Sigma}_{reg} \times \sigma_{SCR}) * w^T} \tag{22}$$

$$E(r) = \bar{r} * w^T \tag{23}$$

$$w_i \geq 0 \tag{24}$$

$$\boldsymbol{\Sigma}_i w_i = 1 \tag{25}$$

and

$$w_i \leq u_i \quad \mathrm{i} \in \{1,2,\dots,6\}. \tag{26}$$

Equation (22) ensures that the resulting SCR (right hand side) stays below a certain threshold (left hand side), while the portfolios are optimized with regard to standard deviation. The SCB thereby serves as an upper boundary and is given exogenously in practice by the capitalization of an individual insurance company. By varying the SCB, it is now possible to derive the optimal portfolio allocation, given a certain capital budget. Technically, the introduction of Equation (22) represents a quadratic constraint in the quadratic optimization problem.

We compute a set of 10.000 portfolios (i.e. target returns) for all three optimization problems, whose compositions are shown in Figure 1 in the next section. In order to reduce the runtime of the optimizations, especially for the more complex problem with a quadratic objective and quadratic restriction, we employ the fast trust-region-reflective algorithm introduced by Coleman and Li (1996).

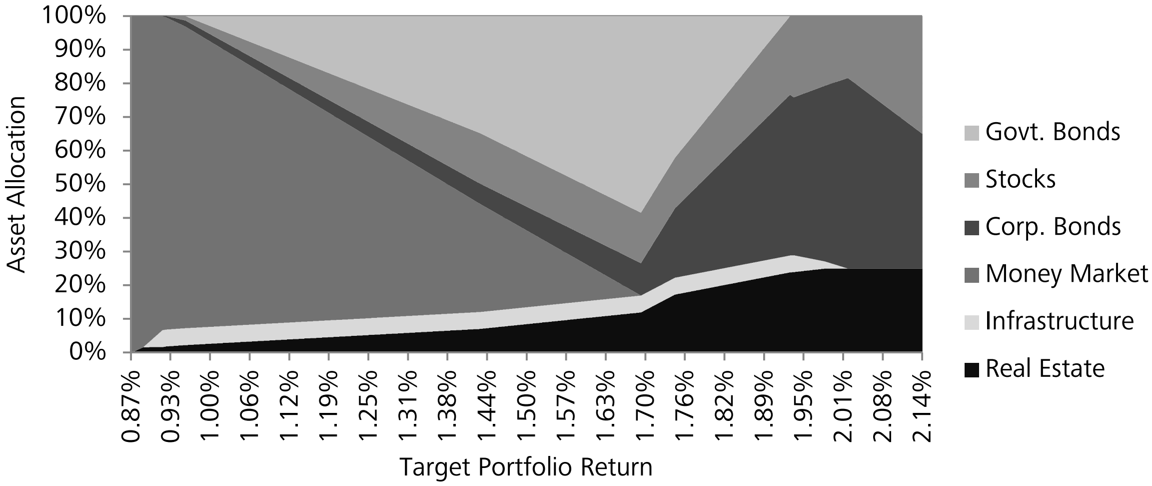
## 3.6 Results

The upper section in Figure 1 illustrates the portfolio allocations using the standard Markowitz optimization technique, as described in the previous section. Since the subset of efficient returns may differ for the STD- and the SCR-optimization, returns are represented along the whole attainable spectrum. The lowest portfolio target return (corner solution) is determined by the asset class with the lowest expected return, i.e. money market. At the other extreme, the highest portfolio target return is achieved by sequentially increasing the weights of the assets with the highest expected returns, until the individual investment limits are reached.

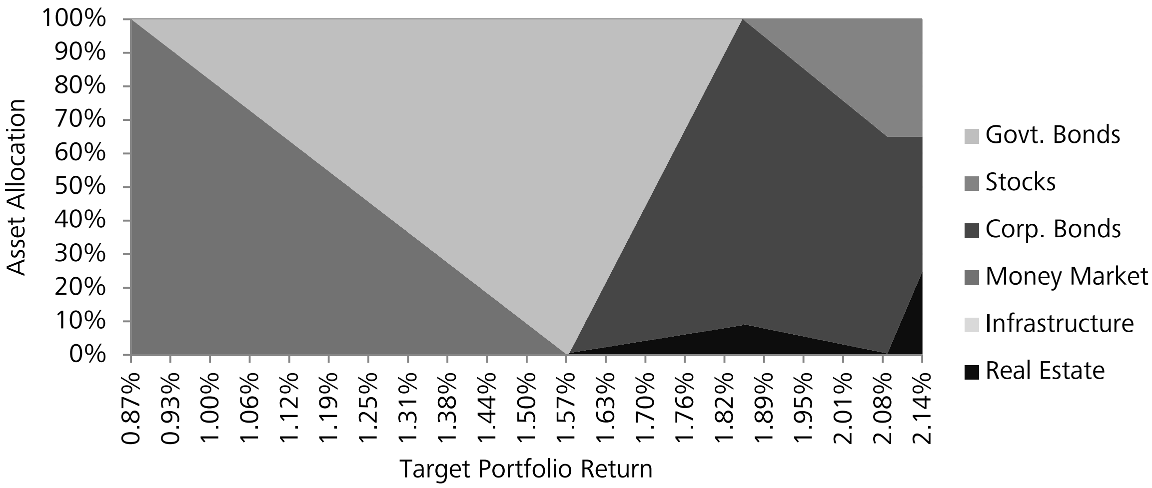
It is evident that almost the entire spectrum of target returns comprises real estate and infrastructure assets. More specifically, for almost all target returns, the allocation of infrastructure assets is only determined by its investment limit, suggesting that even higher (and more efficient) allocations could theoretically occur when investment limits were relaxed. This also holds true for real estate in the case of high target-portfolio returns. Therefore, both assets prove to provide desirable diversification benefits and to deliver high risk-adjusted returns within the mixed-asset portfolio, which is in line with other empirical findings so far. As a conclusion, investors aiming at efficient portfolios with respect to investment risk (in this case the portfolio standard deviation) should consider real estate and infrastructure assets within their investment strategy. However, considering efficient portfolios in terms of capital requirements might yield a different optimal set of assets.

**Figure 1: Efficient Portfolio Allocations**

**(a) STD-optimized Portfolio Allocations**




**(b) SCR-optimized Portfolio Allocations**




Notes: Whereas Panel (a) shows the efficient portfolio allocations with respect to minimizing the standard deviation (STD) and increasing target portfolio returns from left to right, Panel (b) accounts for capital requirements (SCR).

Subfigure (b) in Figure 1 shows the portfolio allocations when the aim of the optimization is to minimize the overall capital requirements. That is, the empirical standard deviations and correlation matrix are replaced by the SCR and the regulatory correlation matrix imposed by EIOPA (including the dynamic SCR for interest-rate-sensitive assets, depending on the current duration gap and the dynamic SCR for the equity risk module). As expected, the optimal set of assets yields a decisively different picture in comparison to the standard Markowitz optimization. While infrastructure assets are completely removed from the optimal portfolio allocation, real estate assets are only part of high-return portfolios. The results can be explained of course by the relatively high SCR for both asset classes and especially by the high regulatory correlation coefficients. Primarily the latter completely distorts the effect of diversification, which can be already assumed by comparing Panels (a) and (b) in Figure 1. Moreover, infrastructure and real estate assets are not subject to interest rate shocks, according to the Solvency II framework, since they do not exhibit any duration. Those asset classes therefore cannot hedge interest rate shocks on the liability side, so that interest-rate-sensitive corporate and government bonds are even more attractive in a portfolio context. Accordingly, bonds make up the major share of the SCR-efficient portfolios, as they are the only assets that are capable of hedging interest rate risk. These initial results already indicate the incorrect parameterization of the Solvency II standard formula, that may lead to inefficient portfolio allocations and thereby increasing portfolio risk. Interestingly, this contradicts the original purpose of the regulation. To illustrate the potential loss of efficiency between the two optimizations, the next figure shows the respective (in-) efficient frontiers.

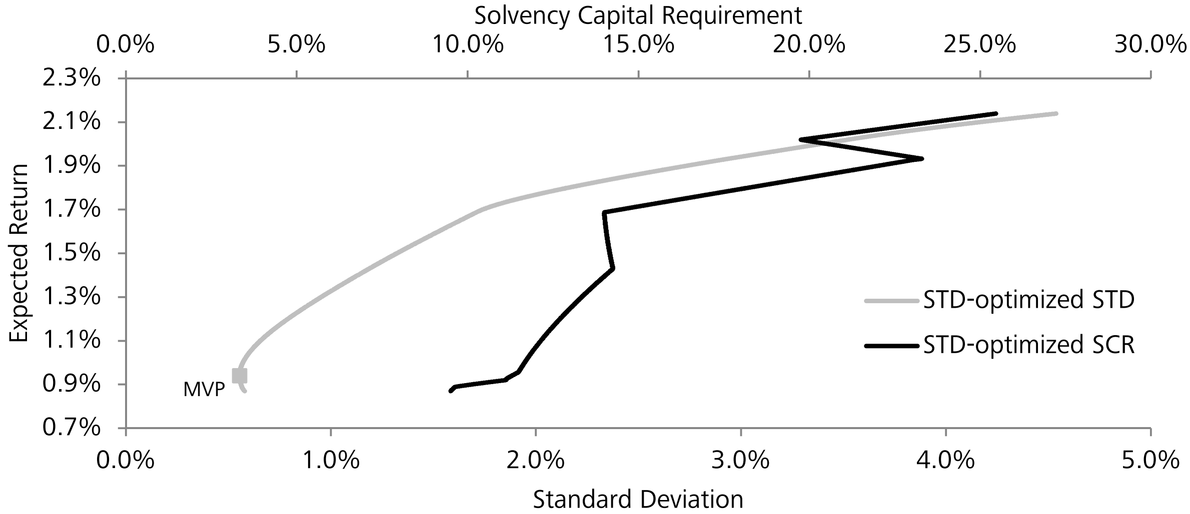
Figure 2 is divided into three different sections. Whereas the upper section contains the efficient frontier for the STD-specific optimization, the middle section shows the SCR-specific optimization and the lower section when both optimizations are blended. All graphs exhibit two different horizontal axes, which must be interpreted according to the respective variable under consideration.

The solid grey line in the upper diagram depicts the efficient frontier for the first optimization problem, using the standard Markowitz approach. It therefore shows the development of portfolio risk depending on the target return (corresponding to Figure 1 a). The solid black line is derived by calculating the SCR for the related STD-efficient portfolios. Note that this line is neither concave nor monotone, thus again indicating the incompatibility between the SCR- and STD-optimization. Hence, the line is not an efficient frontier in the narrow sense. However, in order to judge the degree of incompatibility, it is necessary to calculate the actual SCR-efficient frontier, as shown in the middle section.

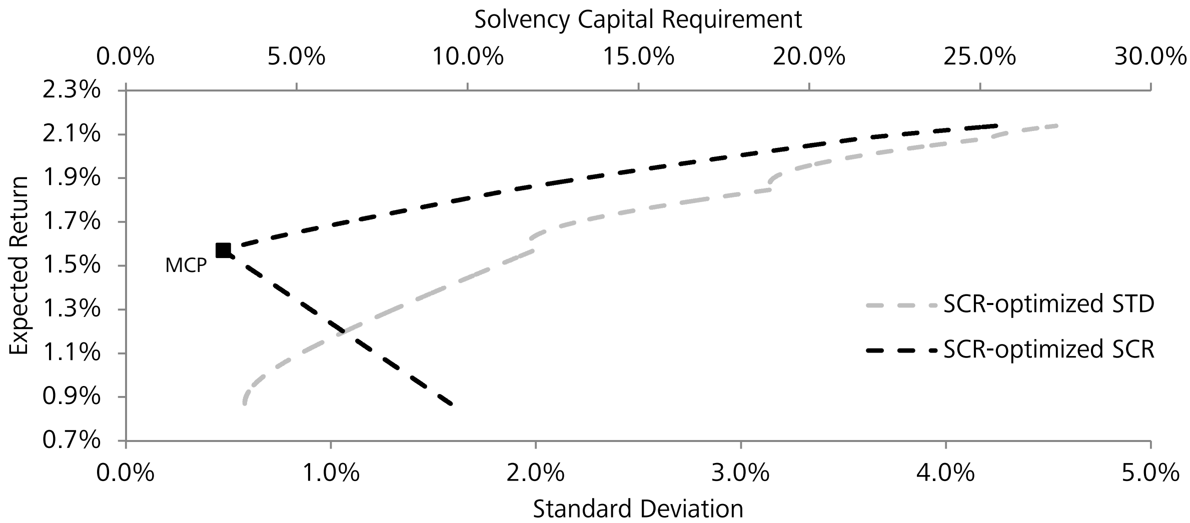
It is obvious that the minimum SCR portfolio (MCP) on the black dashed line – unlike the MVP in the first optimization – is located significantly above the minimum achievable target portfolio return. This point represents the basis for further interpretation of the results. Recalling the descriptive statistics and regulatory requirements in Table 1, the MCP should consist solely of government bonds that are not subject to any SCR and are additionally dominating money market instruments (which are also free of capital charge) in terms of the return-SCR relationship. Moreover, it is evident that the course of the frontier below and above the MCP is almost linear (with concave tendency only), which is due to the very high regulatory correlation figures as well as the monotonously relationship between SCR and returns above the MCP.

**Figure 2: Efficient Frontiers**

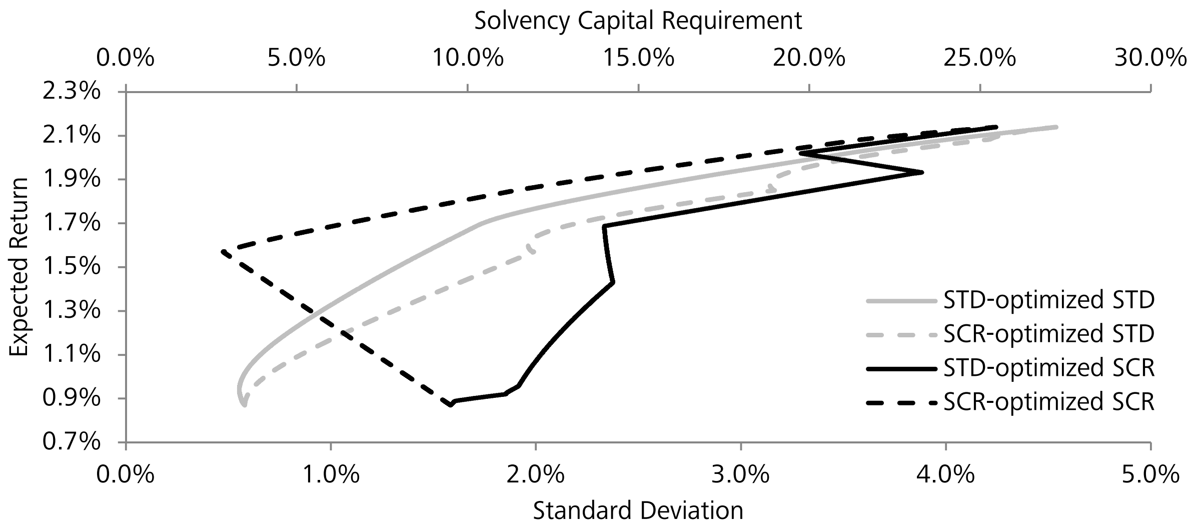
**(a) STD-optimized efficient frontier with resulting SCR levels:**




**(b) SCR-optimized efficient frontier with resulting STD levels:**




**(c) Deadweight loss between both optimization approaches:**



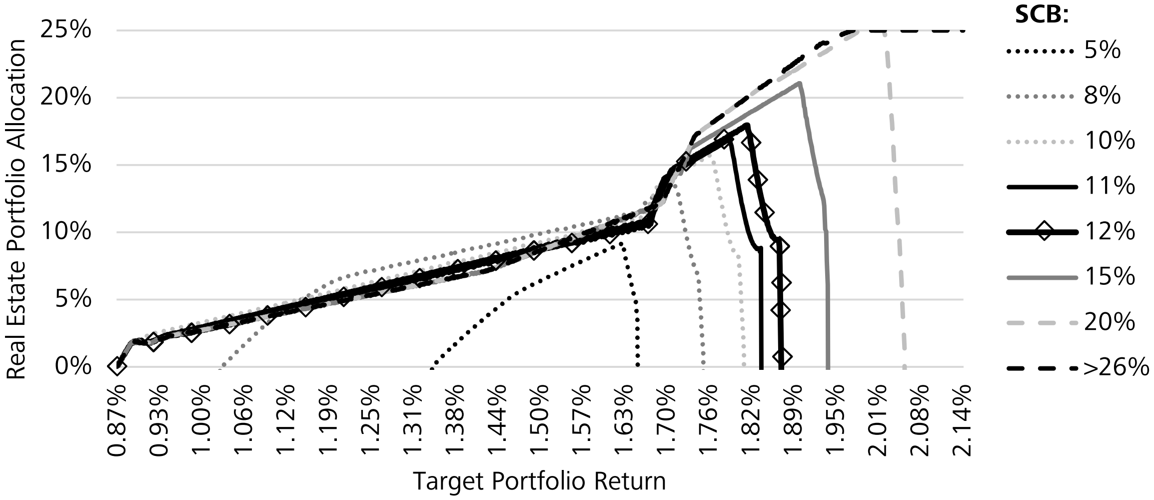
Note that this does not hold true for infrastructure as well as real estate assets, which are (most of the time) not part of the SCR-efficient portfolios. Interestingly, the byproduct of the SCR-optimal portfolios (gray dashed line), the STD-return line, is monotonously and segmentally concave. Hence, there is at least a monotonous relationship between the STD and the return. To conclude, there is no homomorphic relationship between the STD-return concept and the SCR-return concept, which is one major explanation of the incompatibility of the standard formula in the Solvency II Directive. This issue is even exacerbated by the incompatible correlation figures in the case of a SCR-optimization, as well as the neglect of the duration gap in the case of the STD-optimization. [8] To quantify the extent of the incompatibility in terms of portfolio risk, we blend the results of the upper and middle graph into one in Figure 2 (c).

As mentioned, neither the course of the two black lines nor that of the two gray lines in the figure are homomorphic or even congruent. The striking significant deviation between the black lines in the SCR-case can be explained by the strong regulatory preference for government bonds compared to other asset classes. However, one must bear in mind that part of this deviation is due to the scaling of the two different horizontal axes. Ultimately, it is not the area between the two gray or the two black lines that is essential; it is only the horizontal distance between the lines that needs to be interpreted. For instance, given a target portfolio return of 1.8%, the STD-optimal standard deviation is 88 basis points below the corresponding standard deviation according to the SCR-optimization. Using two standard deviations as the relevant measure for quantifying risk, the short fall risk of the portfolio would increase decisively by 176 basis points per annum. [9]

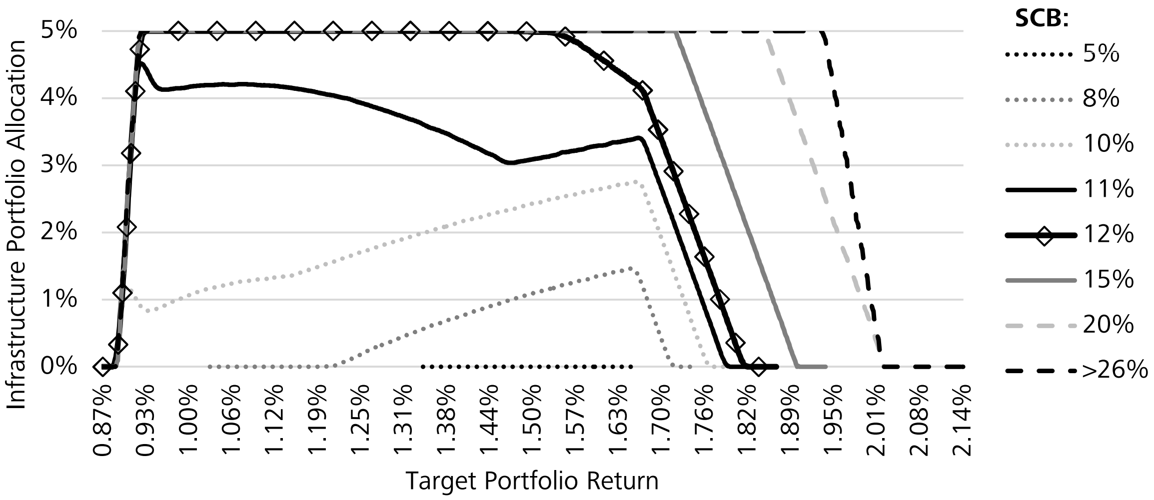
Whether the above mentioned theoretical impact of Solvency II on the portfolio weights of real estate and infrastructure is also relevant in practice depends on the overall capital budget of an individual insurance company and hence, on whether the insurer is forced to minimize the capital requirements at all. While some insurers will certainly be under-capitalized after Solvency II comes into effect, other insurers may already be well-provided with capital. To gain a more realistic picture of the potential practical influence of Solvency II, in the next step, we do not minimize the SCR, but introduce different upper boundaries of given capital budget levels. Depending on the capital budget, we derive optimal portfolios with corresponding efficient frontiers, which are located between the dashed and solid lines in Figure 2. Hence, each given capital budget yields a separate optimization output, i.e. the portfolio weights and corresponding efficient frontiers. For the sake of brevity and with regard to our research objective, we focus on the resulting optimal real estate and infrastructure weights. The results of the optimization are depicted in Figure 3 below.

**Figure 3: Optimal Real Estate and Infrastructure Portfolio Allocation for Different Levels of Solvency Capital Budget (SCB)**

**(a) Real Estate:**




**(b) Infrastructure:**




Notes: Figure 3 illustrates the STD optimal portfolio weights for real estate and infrastructure assets for different given levels of Solvency Capital Budget. The marked line thus represents the average capitalization of European insurers.

The two diagrams show the efficient portfolio weights for real estate and infrastructure investments corresponding to the respective capital budget, ranging from 5% to 26%, as indicated in the legend of the graphic. Note that not the maximum achievable portfolio weights (given a certain target return and capital budget) for both asset classes are shown, but the optimal portfolio weights (still minimizing risk). The area alongside the return-axis thereby indicates the return spectrum, which is reachable for the individual solvency capital. Hence, assuming a capital budget of 5%, only target returns between approximately 1.31% and 1.61% are attainable. On the other hand, the allocations for capital budgets >26% correspond directly to the efficient portfolios as presented in Figure 1 (STD-optimization), i.e. the unrestricted case.

It is striking that, regardless of the individual capital budget, most of the risk-efficient portfolios in the computable return spectrum exhibit a significant share of real estate. Considering the distance between the different capital budgets in the case of high target-portfolio returns, one can observe the development of decreasing optimal real estate weights, with a decreasing capital budget and vice versa. This effect diminishes for medium to low target returns, as the efficient real estate weights are almost congruent, irrespective the budget level. However, it is noticeable that the optimal real estate weights for a capital budget of 8% even exceed the allocations for higher capital budgets. This can be explained by the fact that investments in stocks and infrastructure are not affordable for this particular capital budget, due to the high regulatory capital charges. Accordingly, real estate investments replace these two assets in order to achieve the target returns. However, in terms of portfolio risk, it is crucial that the standard deviation of all portfolios for a capital budget of 8% exceeds the standard deviation of portfolios with a higher capital budget over the entire return spectrum.

Concerning infrastructure investments, the results yield a comparably similar picture at first glance. However, it is not possible to include infrastructure in the efficient portfolios is not possible for all target-portfolio return's, given a capital budget of 5%. Moreover, infrastructure is not necessarily allocated over the whole computable return spectrum for different capital budgets. This is particularly the case for high target-portfolio returns, irrespective of the relevant capital budget and for low target returns in low-capital budget portfolios (5% and 8%). Furthermore, in contrast to the results for real estate, there is a clear monotonous relationship between the capital budget and the efficient infrastructure allocation. That is, a higher capital budget results in a higher infrastructure weight for any target portfolio return and vice versa. This is due to the fact that infrastructure is subject to the highest capital requirements and therefore it is not capable of replacing any other asset class. The results suggest that the individual capital budget of an insurer determines the optimal real estate and infrastructure allocation. To consider the practical relevance and implications, we discuss the obtained findings in the next section with respect to the average capitalization prevailing in the European insurance market.

## 3.7 Discussion and Practical Implications

According to Braun *et al.* (2014), the average capitalization of Swiss insurance companies ranges from approximately 5-12%. Taking into account the information provided by the German Federal Financial Supervisory Authority (BaFin) and the results of the QIS5 released by EIOPA (2011), the average European insurer's capitalization is located at the high end of the range and generally amounts to 12%. Henceforth, in the spirit of Braun *et al.* (2013) and Hoering (2013), we use this figure as the basis for our further interpretation. In addition, it is necessary to determine the most relevant target portfolio returns prevailing in the insurance industry, in order to be able to interpret the results meaningfully. Taking into account the actual average European insurer's asset allocation (cf. e.g. Fitch, 2011; Insurance Europe and Oliver Wyman, 2013) and the empirical asset returns, the most realistic portfolio compositions and therefore the relevant section to be interpreted lies between target returns of 1.7-1.8%. This would result in an annual return of around 7%, which is sufficient to cover the overhead costs and meet the obligations to policyholders.

Recalling Figure 3, the optimal real estate portfolio weights are well above the average current insurer's real estate allocation of 5% for the majority of combinations of target returns and capital budget. Hence, the introduction of Solvency II does not impact on the current trend of increasing real estate allocations, at least not for the average insurer. Considering a specific target return of 1.75% for instance, the risk-optimal real estate weight for 12% SCB amounts to exactly 16%, with rather moderate shifts when varying target return and/or budget within reasonable intervals. It is particularly noticeable that for high target returns, real estate weights are increased to their investment limit once the capital budget allows this. This is due to the risk-reducing properties (i.e. low correlation) which are explicitly accounted for in the optimization problem, since the objective function itself contains the empirical covariance matrix. Real estate therefore proves to be an attractive complement to stocks for sufficiently capitalized insurers.

On the other hand, the optimal infrastructure weight for the mentioned return of 1.75% and SCB of 12% is exactly 1.87%. Other than for real estate, this allocation is extremely sensitive to variations in capital budget or target return. While reducing the SCB constraint to 11% leads to an allocation of only 1.11%, increasing it to 13% leads one of 2.61%. Variation in the target return has an even more severe impact, since the slope of the allocation function is very steep in the relevant section for all relevant SCBs. Interestingly, the average SCB of 12% yields almost exactly the current infrastructure allocation of insurance companies in Europe within the relevant return spectrum. Moreover, at first glance, the sensitivity of infrastructure weights of only 1.11% to 2.61% seems quite insignificant. However, given the average lot size for European infrastructure investment deals of approximately €400 million, with notable deals well exceeding €1 billion (Preqin, 2013), this difference could account for just one single investment in practice. Again, for high target returns, infrastructure weights are increased to their investment limit once the capital budget allows for it. However, the amount of capital needed to ensure the full risk-optimal allocation is much higher than for real estate. Also bear in mind that very high target-return portfolios do not contain infrastructure investments, simply due to their relatively low expected return.

While the previous passages focus solely on the situation of average- and overcapitalized insurance companies, the situation may turn out differently for undercapitalized market participants. According to the QIS5 results of EIOPA (2011), 23.2% of European insurers are at risk of not fulfilling the SCR imposed by Solvency II (i.e. their SCR coverage is below 1.2). Putting aside operational risks (e.g. insufficient reinsurance or high concentration risk), it is likely that these insurers exhibit a SCB below 12%. As a result, these insurers need to act in order to minimize their SCR, e.g. by reducing the allocation of alternative assets. Focusing on the 5%, 8% and 10% SCB-level's real estate and infrastructure allocations, three findings are notable. First, given the attainable target return spectrum, real estate weights of well above 5% are still risk-optimal. Second, risk optimal infrastructure weights are below 2% in the vast majority of cases. Third, the maximum attainable target return is very sensitive to the SCB level. Hence, the capital burden imposed by the Solvency II standard formula creates a competitive disadvantage for already undercapitalized market participants. Compared to overcapitalized competitors, this is likely to force them into a less efficient asset allocation, i.e. limiting infrastructure allocations and also limiting the expansion of real estate allocations. Furthermore, it forces them into low target-return portfolios, i.e. limiting both stock allocations and the expansion of real estate allocations. Both disadvantages might lead to more consolidation among European insurance companies and therefore to further declining competition. Taken together, all these effects undermine the original purpose of Solvency II.

## 3.8 Conclusion

The forthcoming Solvency II Directive introduces a risk-based model for insurers to derive their capital requirements, and thereby changes the set of rules prevailing in the past years. Henceforth, especially undercapitalized insurers might be forced to minimize their economic capital in order to remain competitive in the industry. In addition, even for sufficiently capitalized insurance companies, the Directive might create incentives to reduce capital requirements and potentially lead to a change in the investment patterns. During recent years, especially alternative assets, such as real estate and infrastructure, drew more attention from investors as an alternative source for adequate returns in the current low-interest-rate environment. However, Solvency II might constrain this very development.

To empirically investigate the raised questions, we conduct several portfolio optimizations with respect to the given regulatory requirements of the Solvency II standard formula. The results confirm the current investment trends; real estate and infrastructure investments should play a significant role in the mixed asset portfolio of a representative European insurance company, when the aim of the optimization is to minimize portfolio standard deviation. By contrast, in capital-efficient optimizations, for which the aim of the optimization is to minimize the overall SCR, infrastructure is completely removed from the portfolios over the whole spectrum of target returns and real estate weights are reduced substantially. However, accounting for the actual (not minimum) capitalization of European insurers again yields a different picture. We show that, although the calibration of the capital requirements for alternative assets are obviously inadequate in terms of the risk and SCR relationship, real estate as well as infrastructure investments are still allocated in the risk optimal portfolios, even if realistic capital budgets are considered. In the case of well-capitalized insurance companies, the derived optimal portfolio weights even exceed the observable allocations in practice, which indicates that the introduction of Solvency II is not likely to affect the investment policy with respect to real estate and infrastructure assets. As a consequence, if at all, only small and undercapitalized insurers may be forced to reduce their exposure to alternative investments. Hence, this paper hopefully helps to evaluate the potential effects of Solvency II on a more meaningful basis than in the current and ongoing debates prevailing both in academia and practice. In addition, the paper offers further explanations of the disparity between theoretical optimal and actual alternative asset allocation in practice.

Ultimately, we open up several avenues for further research on related topics. First, the methodology can be used as a basic framework for dealing with capital requirements in portfolio optimization. Further research could, for instance, examine different capital requirement regimes for insurance companies, such as the Standard & Poor's Rating model or the Swiss Solvency Test. Second, there is an ongoing research stream on whether real estate investments exhibit any duration. The same should hold true for infrastructure, as it is also seen as a supposedly interest-rate-sensitive asset. Hence, further studies could account for the respective duration of both assets within the interest rate risk sub-module in the relevant capital charge framework. Lastly, this paper focuses solely on the effects on direct real estate and infrastructure investments. However, more and more capital now flows into debt-like investment vehicles, such as real estate debt funds, which in turn are treated differently under the Solvency II regime. Further research could incorporate these investments instruments in a similar setting.

## 3.9 ENDNOTES

[1] In line with Braun *et al.* (2014), we do not account for the possible "symmetric adjustment mechanism" of -7% and use the base levels of the two stresses (cf. SCR 5.37 in EIOPA (2012)).

[2] The data frequency and sample period is limited to quarterly observations, due to the frequency of the benchmark index of infrastructure performance.

[3] The IPD U.K. Property Total Return Index covers one of the most transparent and liquid real estate markets in the world. Data is available in high frequency and for a sufficiently long time period. For these reasons, the regulator also decided to use exactly this index in order to map real estate performance in Europe. We deem the simple unsmoothing technique to be sufficient for our research purposes.

[4] The index covers transactions in all economic and social infrastructure sectors, i.e. transportation, energy (oil, water, gas), communication, waste recycling, healthcare and education. All included sectors are in accordance with the definition of infrastructure from Wagenvoort *et al.* (2010) and Weber and Alfen (2010).

[5] We use this index to enhance the sample period, as there is no other European corporate bond index with a comparably long history. The European corporate bonds index provided by BofA Merrill Lynch (Code: MLEXPEE) only dates back to 1996, but shows very similar risk/return profile and correlation patterns. Therefore, our results are unlikely to be affected by the choice of data set. In addition, other studies have also chosen this index for similar research purposes (cf. e.g. Braun *et al.*, 2013)

[6] We thank William le Noble from Citigroup for providing the information.

[7] Strictly speaking, one should differentiate between the free and restricted assets of the insurance company. The free assets thereby equal the firms's equity capital and are not subject to regulatory investment limits. These limits are only relevant for the restricted assets, which back the insurer's technical provisions. For reasons of simplicity, we assume the free assets to be allocated in the same manner as restricted assets.

[8] However, negative interest rate shocks, as prescribed by the regulator, are not expected during the current structural low-interest-rate environment and are therefore not accounted for in the Markowitz-optimization. In addition, to reliably incorporate interest rate risk into the optimization algorithm would require detailed assumptions about the balance sheet of the respective insurance company.

[9] This corresponds to a Value-at-Risk of approximately 95% assuming normal i.i.d. returns.

## 3.10 APPENDIX

**Appendix 1: Altered Term Structure for Interest Rate Risk**

| Maturity $t$ (years) | Relative Change $s^{up}$ $(t)$ | Relative Change $s^{down}$ $(t)$ |
|---|---|---|
| 0,25 | 70 % | -75 % |
| 0,5 | 70 % | -75 % |
| 1 | 70 % | -75 % |
| 2 | 70 % | -65 % |
| 3 | 64 % | -56 % |
| 4 | 59 % | -50 % |
| 5 | 55 % | -46 % |
| … | … | … |
| 20 | 26 % | -29 % |
| 90 | 20 % | -20 % |

Notes: This table shows the relevant stress factors $s^{u/down}$ for individual maturities $t$

## Appendix 2: Spread Risk Factors for Bonds

| Duration (years) | Credit Quality Step 0 | 1 | 2 | 3 | 4 | 5 | 6 | Unrated |
|---|---|---|---|---|---|---|---|---|
| < 5 | 0.9% × D | 1.1% × D | 1.4% × D | 2.5% × D | 4.5% × D | 7.5% × D | 7.5% × D | 3.0% × D |
| 5-10 | 4.50% + 0.53% × (D-5) | 5.50% + 0.58% × (D-5) | 7.00% + 0.58% × (D-5) | 12.50% + 1.50% × (D-5) | 22.50% + 2.51% × (D-5) | 37.50% + 4.20% × (D-5) | 37.50% + 4.20% × (D-5) | 15.00% + 1.68% × (D-5) |
| 10-15 | 7.15% + 0.50% × (D-10) | 8.40% + 0.50% × (D-10) | 10.50% + 0.50% × (D-10) | 20.00% + 1.00% × (D-10) | 35.05% + 1.80% × (D-10) | 58.50% + 0.50% × (D-10) | 58.50% + 0.50% × (D-10) | 23.40% + 1.16% × (D-10) |
| 15-20 | 9.65% + 0.50% × (D-15) | 10.90% + 0.50% × (D-15) | 13.00% + 0.50% × (D-15) | 25.00% + 1.00% × (D-15) | 44.05% + 0.50% × (D-15) | 61.00% + 0.50% × (D-15) | 61.00% + 0.50% × (D-15) | 29.20% + 1.16% × (D-15) |
| >20 | 12.15% + 0.50% × (D-20) | 13.40% + 0.50% × (D-20) | 15.50% + 0.50% × (D-20) | 30.00% + 0.50% × (D-20) | 46.55% + 0.50% × (D-20) | 63.50% + 0.50% × (D-20) | 63.50% + 0.50% × (D-20) | 35.00% + 0.50% × (D-20) |

Notes: This table presents the spread risk factors for bonds and loans, depending on individual credit quality and duration.

## Appendix 3: Solvency II Market Risk Correlation Matrix

| | Interest | Equity | Property | Spread |
|---|---|---|---|---|
| Interest | 1 | | | |
| Equity | 0 / 0.5 | 1 | | |
| Property | 0 / 0.5 | 0.75 | 1 | |
| Spread | 0 / 0.5 | 0.75 | 0.5 | 1 |

Notes: The table depicts the regulatory correlation figures for the upward (left) and downward (right) scenario

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# 4 Can Common Risk Factors Explain Infrastructure Equity Returns? Evidence from European Capital Markets

**Abstract**

This is the first paper to test the ability of conventional asset pricing models to explain the excess returns of European infrastructure stocks. Specifically, we firstly run the well-known Fama and French (1993) three-factor model, including three common stock market factors (market risk, size risk, value risk), and subsequently augment the model with two common bond risk factors (term and default risk), as infrastructure firms should be closely related to bond markets. The times-series regressions span the period from July 1992 to June 2014 and are conducted using an individually created infrastructure equity data set. With the help of an intensive screening process, we only include those infrastructure stocks that in fact own and/or operate physical infrastructure. The results reveal that the three-factor model is unable to capture most of the variation in infrastructure returns. Therefore, bond risk factors should be included in asset pricing models, in order increase the goodness of fit, as infrastructure stocks prove to be sensitive to interest rate changes. Nevertheless, even the augmented asset pricing model leaves a substantial part of the variance unexplained, thus indicating that infrastructure firms exhibit a high level of idiosyncratic risk. In addition, the results suggest that there may be further risk factors which should be investigated in future studies.

## 4.1 INTRODUCTION

Historically low interest rates and capital market volatility have resulted in a global demand of (institutional) investors for alternative asset classes. In particular, investors seek assets that are not heavily exposed to economic cycles and capable of generating stable returns with some inflation protection. These investment characteristics are mainly attributable to infrastructure investments, so that this emerging asset class has enjoyed more and more investor attention in the past decade. A further major driver for the infrastructure sector is the worldwide need to invest in new and to maintain existing infrastructure assets, which poses significant challenges to governments. The European Commission (2013) estimates that the investment needs for European infrastructure until 2020 alone amount to roughly €1 trillion, without taking into account water utilities, waste management and social infrastructure. Hence, the true figure would even be substantially higher. Accordingly, other studies even project total European infrastructure investment needs of more than €8.4 trillion by 2030, which would result in an average annual volume of roughly €400-500 billion (Inderst, 2013).

Given the tight fiscal budgets, it is clear that governments are unable to fund these infrastructure projects alone. Hence, more and more infrastructure assets are privatized, either through initial public offerings, public sales, or public-private partnerships (PPP) (RREEF, 2011). For instance, more than 750 privatizations in the utilities, transportation and telecommunications sector have taken place in Europe over the years 1980 to 2013. [1] Globally, the European infrastructure sector accounts for almost half of all infrastructure transactions in the last few years, thus remaining the most significant region for the infrastructure asset class worldwide (Preqin, 2013). As a consequence, the infrastructure investment volumes in Europe, both of listed and unlisted investment vehicles, are rising steadily. The situation is even aggravated by the deleveraging of banks, which in turn increases the need for more equity capital. Within private infrastructure finance, listed infrastructure companies therefore represent one major source of alternative funding. In Europe alone, approximately $10 bn of infrastructure capital has been raised in European stock markets in the years 2006-2011 (RREEF, 2011).

It is therefore surprising that although the European infrastructure investment market is of particular importance, the empirical research on infrastructure investments is almost exclusively focused on the U.S. and Australian markets. In addition, very few studies deal with the risk and return relationship of infrastructure investments in general. Therefore, this present study aims at filling a very relevant gap in the literature. Specifically, this is the first paper to test whether the traditional and most widely-used three-factor model of Fama and French (1993) is capable of capturing the shared variation in European infrastructure equity returns. Moreover, we also include two additional common bond risk factors in our asset pricing model. The rationale behind this is the fact that the underlying cash flows of infrastructure companies, with its long-term fixed nature, have properties relatively similar to bonds. Moreover, infrastructure firms are typically highly levered, so that risk factors related to the term structure of interest rates may also convey valuable information on the pricing of infrastructure firms. The empirical analysis in this paper spans the period from July 1992 to June 2014 and is conducted on the basis of an individually created data set of all European “pure-play” infrastructure companies. The results obtained are especially beneficial in times of increasing privatizations, in order to derive the cost of capital of infrastructure firms more efficiently.

The following section reviews the relevant empirical literature on the asset pricing of infrastructure companies. Section 3 explains the data screening process, in order to derive the individual infrastructure equity data. Section 4 outlines the methodology and research design applied in the study and the results are presented in Section 5. The final section concludes.

## 4.2 Literature Review

In general, the empirical literature on infrastructure asset pricing is still scarce but has been attracting more and more attention over the last few years. The available literature can be divided into two distinct research streams. On the one hand, there are numerous studies in the finance and economics literature on infrastructure subsectors, e.g. in the oil and gas sector. On the other hand, more recent studies adopt the definition of (economic) infrastructure and subsume the sectors of transport, utilities and telecommunications as infrastructure investments. Accordingly, we follow this distinction and present the most relevant studies with respect to our research focus within this section.

O’Neal (1998) was among the first to conduct asset pricing tests of electric utility stocks. More precisely, he examines the determinants of interest rate sensitivity of electric utility stocks and reveals that the rating of a utility’s debt is the predominant driver. Moreover, large utilities appear to be more interest rate sensitive than smaller ones. One of the first studies on the pricing of Canadian oil and gas companies is that of Sadorsky (2001), who uses a multifactor market model to test the relationship between the returns of an oil and gas stock index and several risk factors. The author finds that market risk, oil price, term premium and exchange rate factors show a large and significant impact on the returns of oil and gas companies. Boyer and Filion (2007) extend the work of Sadorsky (2001) and examine common and fundamental factors in the individual stock returns of Canadian oil and gas companies. They identify five common factors (interest rates, exchange rate, market return, oil prices, and natural gas prices), as well as five fundamental factors (proven reserves, volume of production, debt level, operational cash flows, and drilling success) to explain the stock returns. In addition, they find the determinants to be dependent on the respective business model, i.e. oil versus gas companies, or integrated energy companies versus independent producers. Likewise, Mohanty and Nandha (2011) investigate the oil risk exposure of the U.S. oil and gas sector. They run asset pricing tests using the well-known Carhart (1997) four-factor model, augmented by oil price and interest rate factors, and find changes in oil prices to be a further positively significant factor in explaining the stock returns of the oil and gas sector. Ultimately, Ramos and Veiga (2011) run asset pricing tests for an international sample of oil and gas companies and confirm the previously mentioned results. Likewise, Bianconi and Yoshino (2014) examine the risk factors and value at risk in publicly traded companies in the nonrenewable energy sector. They additionally include company-specific risk factors, that is company size and debt-to-equity ratio, and find these factors also to be significantly priced, too.

Besides the abovementioned publications, there are also a modest number of studies with a specific focus on infrastructure investments. Rothballer and Kaserer (2012) were the first to investigate the risk profile of listed infrastructure investments at the company level. Based on a unique dataset of international infrastructure equities, they find infrastructure companies to be less exposed to market risks (i.e. they exhibit lower betas) compared to general equities. In particular, utilities are found to be less risky than transportation and telecommunications. However, all sectors have shown a high level of idiosyncratic risk, which contradicts the general perception of infrastructure investments as being less risky than other investments.

Bianchi *et al.* (2014) model the long-term U.S. infrastructure return behavior by re-constructing several relatively short U.S. listed infrastructure indices, using a five-factor asset pricing model. More specifically, they employ recent empirical data to construct a long-term return time series of infrastructure investments that can be used subsequently in a portfolio optimization framework. The authors find that approximately half of the variation in infrastructure indices' returns can be explained by the four systematic risk factors of Carhart (1997). The empirical results further show that infrastructure returns exhibit moderate market betas, and on average, a positive loading on the value-risk factor, indicating that listed infrastructure companies are rather value-stocks than growth stocks. Bird *et al.* (2014) run an extended version of the standard Fama-French asset pricing model and show the existence of excess returns in U.S. and Australian infrastructure investments using various infrastructure index series. In addition, infrastructure investments show, on average, defensive market betas. Moreover, their results suggest that infrastructure investments in the utilities sector are capable of hedging inflation. Given the relatively low explanatory power of their model, the authors conclude that there must be additional factors, such as a regulatory risk premium that play a vital role in explaining the variance of infrastructure equity returns.

The most recent and relevant publication with respect to our research purpose is that of Ammar and Eling (2015), who identify the common risk factors in the returns of U.S. infrastructure companies. They augment the traditional Fama and French (1993) three-factor model with additional variables, as the traditional model is not capable of sufficiently explaining the variation in infrastructure returns, although all factors prove to be significant variables. More precisely, they add common bond risk factors, as well as alternative risk factors to their asset pricing model. The results show that infrastructure companies exhibit low market betas and a significantly negative loading on the size factor, indicating that infrastructure companies tend to behave like large caps. In addition, they reveal that infrastructure companies exhibit an additional leverage premium that is not already included in the value factor. On average, infrastructure investments also tend to be highly interest rate sensitive according to their findings. However, it is crucial to mention that the adjusted $R^2$ values in their regression models only increase marginally and still leave approximately 40% of the variance in infrastructure returns unexplained. Moreover, the screening process for identifying pure-play infrastructure companies is less restrictive than Rödel and Rothaller (2012), so that the dataset is assumed also to include infrastructure-related companies which might slightly distort the results.

## 4.3 Infrastructure Data Issues

As the literature review shows, most studies are based on infrastructure index data, which raises several issues in terms of reliability. Firstly, the publicly available infrastructure stock indices do not necessarily share the same definition of infrastructure, so that comparability is compromised. Secondly, most index series were only launched recently, and therefore date back only a few years. Ultimately, the indices contain only a few infrastructure firms, meaning that they do not offer a valid starting point (i.e. long constituent list) for retrieving sufficient individual infrastructure equity data.

In order to analyze listed infrastructure companies in entirety, we create an individual dataset of listed infrastructure companies in 16 European countries. In accordance with Fama and French (2012), we only include companies listed in Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK. The screening process follows Rödel and Rothballer (2012), who identify all traded and defunct European infrastructure companies, based on the Standard Industrial Classification (SIC) and General Industry Classification Standards (GICS) codes. Hence, this procedure reflects the market portfolio more effectively and is more suitable for analyzing potential small-size effects, since no size restrictions are introduced. We include all sectors of economic infrastructure, i.e. transport (ports, airports, pipelines, railways and highways), utilities (generation, transmission, and distribution of electricity; gas and water) and telecommunication (fixed line, satellite, cable). The definition of infrastructure is based on several industry publications (Inderst, 2009; RREEF, 2005; Colonial First State, 2006) and index providers (MSCI, S&P), since no generally accepted definition of infrastructure is available to date.

All active and inactive publicly traded European general equities are collected from Thomson Reuters Datastream, and only those carrying an infrastructure related SIC or GICS code remain in the sample. Given the fact that the infrastructure definition has a horizontal industry perspective, the filtered sample also includes a decisive share of companies along the vertical value chain that do not necessarily own or have a concession for physical infrastructure assets. Therefore, other infrastructure-related companies, such as service providers (e.g. aircraft cleaning), construction firms, capacity resellers (e.g. electricity resellers) or network services (e.g. railways without their own tracks), are excluded from the sample by individually screening their asset bases ("asset test") and revenue ("revenue test"). Only companies that generate more than 50% of their revenue with core infrastructure are included in the final sample. The relevant information was obtained from several sources, such as Thomson Worldscope (business descriptions and segment reporting data), Google Finance, annual reports and webpages.

Ultimately, we employ a static and dynamic screening process, as suggested by Ince and Porter (2006) and Schmidt *et al.* (2011), in order to ensure reliable individual equity return data. In the course of the static screening process, we only include companies that are located in the domestic market and listed on major stock exchanges. Moreover, duplicates, non-common equities and wrongly classified common equities such as preferred stocks, closed-end funds, shares of beneficial interest, profit participation certificated, warrants and ETFs are excluded. According to the dynamic screening process, each company must fulfill the following criteria. Firstly, there must be an observable market value of equity for December of year $t$ and June of year $t-1$, as well as a book equity for fiscal year $t-1$. In addition, each company needs to exhibit a positive book-to-market ratio. Lastly, penny stocks, that is, companies with a share price less than €1, are also not included in the final data set. Again, the required information is retrieved from Thomson Reuters Datastream, that is, we collect total return indices, share prices, number of shares and the market and book value of equity for each infrastructure company. All variables are, if required, denominated in Euros.

**Table 1: Regional and Sector Breakdown**

| | Infrastructure | Transport | Telecom | Utilities |
|---|---|---|---|---|
| Austria | 8 | 1 | 1 | 6 |
| Belgium | 11 | 1 | 3 | 7 |
| Denmark | 4 | 1 | 1 | 2 |
| Finland | 6 | 0 | 4 | 2 |
| France | 28 | 7 | 9 | 12 |
| Germany | 48 | 7 | 8 | 33 |
| Greece | 8 | 2 | 3 | 3 |
| Ireland | 1 | 0 | 1 | 0 |
| Italy | 41 | 9 | 7 | 25 |
| Netherlands | 9 | 1 | 7 | 1 |
| Norway | 5 | 0 | 2 | 3 |
| Portugal | 6 | 1 | 3 | 2 |
| Spain | 22 | 2 | 4 | 16 |
| Sweden | 12 | 0 | 5 | 7 |
| Switzerland | 18 | 6 | 1 | 11 |
| United Kingdom | 58 | 3 | 13 | 42 |
| | **285** | **41** | **72** | **172** |

Table 1 contains the regional and sector breakdown of the final European infrastructure sample in this study. After the screening processes, the total sample amounts to 285 infrastructure companies in 16 European countries, with a strong emphasis on utilities. Moreover, most companies are listed in (relatively) mature infrastructure markets, such as the UK, Germany, France and Italy, resembling the overall infrastructure market development in Europe. It is also striking that most listed companies in the transportation sector are located in Italy and France, which might be due to the relatively advanced state of privatization in these two countries. However, it is worth mentioning that the sample does not cover the whole infrastructure investment universe. Social infrastructure (such as schools or hospitals), unlisted investment vehicles, as well as Public Private Partnerships (PPP) are not included in the analysis. The dataset covers the 22-year period from July 1992 to June 2014, yielding 264 monthly observations. Given the relatively large number of individual infrastructure stocks and the sufficiently long time series, the data sample can be used in the following asset pricing tests.

## 4.4 Methodology and Research Design

We follow Fama and French (1993, 1996) and construct infrastructure test portfolios from the 285 individual infrastructure stocks. At the end of June of each year $t$, each infrastructure stock is sorted according to its size and book-to-market (BE/ME) ratio. Size is defined as a company's market value of equity, which is calculated by multiplying the stock price by the number of shares outstanding at the end of June in year $t$. BE/ME is calculated by dividing the book value of equity (common stocks plus deferred taxes) at the fiscal year $t-1$, by its market value at the end of December in years $t-1$. We then run a two-sequential sorting procedure to construct infrastructure test portfolios.

To create six infrastructure test portfolios, we first rank all infrastructure stocks according to size at the end of June in year $t$. The median is used to divide the sample into two portfolios based on a 50:50 split, i.e we obtain a sample of small (S) and big (B) infrastructure stocks. In the second step of the sorting procedure, all stocks within the small and big infrastructure portfolio are assigned to three different BE/ME portfolios based on a 30:40:30 split. Hence, approximately 30% of the infrastructure stocks with high and low BE/ME ratios are sorted to the high (H) and low (L) portfolios and 40% of the infrastructure stocks are allocated to medium (M) portfolios. Thus, the sorting procedure leads to six infrastructure test portfolios formed from the intersection of the two size and three BE/ME groups. The sorting procedure is repeated in June of each year $t$ and the portfolio composition is held constant for the next 12 months. Ultimately, equally-weighted monthly returns are calculated for each of the six test portfolios and the risk-free rate is subtracted, in order to obtain portfolio excess returns.

To examine whether the systematic stock market risk factors are able to explain the excess returns of the infrastructure portfolios in a time-series setting, we first employ the conventional Fama and French (1993) three-factor model and regress the excess returns of the infrastructure portfolios on the stock risk factors related to market, size and BE/ME. The model can be formally written as:

$$R_{i,m} - R_{f,m} = \alpha_i + \beta_i(R_{M,m} - R_{f,m}) + \delta_i SMB_m + \gamma_i HML_m + \varepsilon_{i,m} \tag{1}$$

$$i = 1,2,\ldots,6 \text{ and } m = 1,2,\ldots,264$$

where $R_{i,m}$ is the return on portfolio $i$ in month $m$, $R_{f,m}$ and $\beta_{M,m}$ are the risk-free rate and the market return in month $m$, respectively. $SMB_m$ is the Fama and French (1992,1993) size risk factor which equals a zero-investment strategy that goes long in stocks with small market capitalization and short in stocks with large market capitalization. Likewise, $HML_m$ is the value risk factor pertaining to the BE/ME ratio, i.e. a zero investment strategy that goes long in value stocks (high BE/ME) and short in growth stocks (low BE/ME). $\beta_i$, $\delta_i$ and $\gamma_i$ are the estimated factor loadings on the infrastructure portfolio $i$, using ordinary least squares (OLS) time-series regressions. $\alpha_i$ represents the intercept term or constant of infrastructure portfolio $i$ and can be interpreted as the average risk-adjusted performance. $\varepsilon_{i,m}$ is the error term of infrastructure portfolio $i$ in month $m$, which is assumed to have a zero mean and no correlation with the other explanatory variables.

We subsequently augment the three-factor model with two additional bond market risk factors as proposed by Fama and French (1993). The two bond market factors thereby proxy unexpected changes in interest rates and shifts in the probability of default. The five-factor model, including all common risk factors, can then be formulated as:

$$R_{i,m} - R_{f,m} = \alpha_i + \beta_i(R_{M,m} - R_{f,m}) + \delta_i SMB_m + \gamma_i HML_m + \psi_i TERM_m + \omega_i DEF_m + \varepsilon_{i,m} \quad (2)$$

$$i = 1,2,\ldots, 6 \text{ and } m = 1,2,\ldots, 264$$

where $TERM_m$ captures the unexpected changes in the slope of the yield curve, i.e. unexpected shifts in interest rates. $TERM_m$ is calculated as difference between the month $m$ holding-period return of long-term governments bonds and the risk-free rate ($R_{f,m}$). $R_{f,m}$ proxies the general level of expected returns on bonds. Hence, $TERM$ can be seen as the unexpected return of long-term government bonds due to shifts in interest rates. $DEF_m$ represents the second common bond risk factor (default factor) that proxies the shifts in the probability of default on corporate bonds. $DEF_m$ is calculated as difference between the month $m$ holding-period return of long-term corporate bonds and the long-term government bonds return. Therefore, $DEF$ should have a zero mean in a default-free economy.

In general, a well-specified asset pricing model that captures the common risks should exhibit significant betas, a high $R^2$ and statistically insignificant constants. With regard to the suggestions of Lewellen *et al.* (2010), a special focus should lie on the intercept terms, since apparently high $R^2$ do not necessarily favor one asset pricing model over another. Hence, we also test the null hypothesis of whether the intercepts of our six test portfolios are jointly equal to zero, by using the F-test of Gibbons, Ross and Shanken (1989). The so-called GRS F-statistic allows for a direct comparison of both asset pricing models. The better model should observe a lower GRS F-statistic, i.e. smaller intercepts in absolute terms.

Data for the European stock risk factors and the risk-free rate are retrieved from Kenneth French's website (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html). The regional focus of the European factor construction is in line with the countries included in our European infrastructure data set. The returns on European long-term government bonds are obtained by using the EU Citigroup WGBI Europe 10+Y total return index. To proxy the European long-term government bonds performance, we use the BOFA ML EUR CORP 10+Y total return index. However, since this index only dates back to 1996 and no other representative European corporate bonds index is available for the entire sample period, we use the US Citigroup USBIG Corporate 10+Y for the first four years of our empirical analysis. [2]

## 4.5 Empirical Results

### 4.5.1 Descriptive Statistics

Table 2 summarizes the descriptive and summary statistics for the dependant and explanatory variables in our empirical analysis. The descriptive statistics for the six infrastructure test portfolios are presented in Panel A of the table. The test portfolios are sorted from small capitalized infrastructure companies with high a BE/ME ratio (S/H), to big infrastructure companies with a low BE/ME ratio (B/L). The value effect for infrastructure companies is well reflected in the descriptive statistics, with decreasing average excess returns alongside decreasing BE/ME ratios. For instance, small infrastructure companies with a high BE/ME ratio (S/H) exhibit mean monthly returns of 0.59%, whereas small infrastructure companies with a low BE/ME ratio (S/L) only yield 0.10%. In contrast, the descriptive statistics counteract the size effect for infrastructure companies. While small companies generally are expected to exhibit a higher raw return than large ones, infrastructure companies do not show the common pattern and large companies outperform small infrastructure companies on average. This particularity might be explained by the specific features of large infrastructure companies. Usually, these companies operate in a monopolistic environment and might therefore be able to capitalize on this competitive market advantage, thus yielding comparably higher returns.

Concerning the average firm characteristics of the specific infrastructure test portfolios, it is evident that there is a large discrepancy between the average size of small and large infrastructure companies. The average size ranges from a market capitalization of approximately €184 million up to over €11 billion. The high market capitalization can be explained by the relatively high proportion of utility companies in the data sample. In addition, the data sample includes the key players in the European telecommunications sector, that also exhibit very high market capitalizations. On the other hand, the average BE/ME ratio in the test portfolios ranges from 1.51 to 0.27. According to other European asset pricing studies, the mean BE/ME ratio for the general European stock market amounts to approximately 0.85 (Schulte *et al.*, 2011; Walkshaeusl and Lobe, 2014). Hence, European infrastructure companies cannot clearly be labeled as value or growth stocks according to the descriptive statistics. Ultimately, the sorting procedure ensures a sufficient average number of stocks of 18.82 to 25.27 in the test portfolios.

**Table 2: Descriptive and summary statistics for dependant and explanatory variables**

| *Panel A: Dependant Variables* | | | | | | |
|---|---|---|---|---|---|---|
| Variable | S/H | S/M | S/L | B/H | B/M | B/L |
| Mean | 0.59% | 0.44% | 0.10% | 0.89% | 0.88% | 0.62% |
| Std. Dev. | 2.91% | 3.25% | 3.25% | 4.16% | 4.05% | 4.01% |
| *t*-value | 3.30 | 2.21 | 0.52 | 3.46 | 3.55 | 2.51 |
| Min | -9.13% | -14.93% | -18.11% | -10.96% | -10.89% | -12.45% |
| Max | 8.09% | 14.62% | 11.61% | 13.24% | 10.10% | 14.06% |
| Skewness | -0.54 | -0.36 | -1.16 | -0.23 | -0.33 | -0.10 |
| Curtosis | 3.72 | 7.06 | 8.40 | 3.14 | 3.04 | 3.99 |
| Average SIZE | 184.16 | 259.84 | 258.52 | 11,009.54 | 9,883.99 | 11,800.59 |
| Average BE/ME | 1.51 | 0.75 | 0.36 | 1.06 | 0.55 | 0.27 |
| Average # of stocks | 19.68 | 23.18 | 18.82 | 21.64 | 25.27 | 21.23 |
| Observations | 264 | 264 | 264 | 264 | 264 | 264 |
| *Panel B: Explanatory Variables* | | | | | | |
| Variable | RM-Rf | SMB | HML | TERM | DEF | |
| Mean | 0.61% | 0.00% | 0.48% | 0.47% | -0.05% | |
| Std. Dev. | 5.05% | 2.30% | 2.49% | 2.11% | 1.53% | |
| Min | -22.14% | -6.94% | -9.57% | -5.52% | -6.29% | |
| Max | 13.78% | 9.31% | 10.96% | 6.88% | 4.57% | |
| *t*-value | 1.98 | 0.03 | 3.10 | 3.64 | -0.51 | |
| *Correlations* | | | | | | |
| RM-RF | 1.00 | | | | | |
| SMB | -0.15 | 1.00 | | | | |
| HML | 0.19 | -0.08 | 1.00 | | | |
| TERM | -0.10 | -0.12 | -0.01 | 1.00 | | |
| DEF | 0.30 | 0.17 | 0.09 | -0.51 | 1.00 | |

Notes: This table presents the descriptive and summary statistics for the infrastructure portfolio excess returns (dependant variables) and risk factors (explanatory variables) over the period July 1992 ($m$=1) to June 2014 ($m$=264); Panel A documents the monthly time-series statistics for the portoflio excess returns, the average SIZE, bookt-to-market (BE/ME) and number of stocks in the test portfolios; S and B denote small and big size portfolios and H, M, L high, medium and low BE/ME portfolios, respectively; Panel B shows the descriptive statistics for the risk factors and the corresponding correlation matrix.

Panel B of Table 2 shows the average risk premiums for the explanatory variables. On average, the market excess returns amount to 0.61% on a monthly basis, which is lower than the excess returns of the large infrastructure test portfolios. Even more interesting is the fact that the size risk premium in the European stock market seems to have disappeared completely. This might be a further factor explaining the reverse pattern in the returns of small and large infrastructure test portfolios. On the other hand, the average value risk premium amounts to 0.48% per month and is significantly different from zero (*t*-value 3.10). Likewise, the average risk premium associated with the term structure risk premium $TERM$ is also approximately 0.5% per month and also significantly different from zero ($t$-value 3.64). The term premium is notably high in comparison to other studies (e.g. Peterson and Cheng-Ho, 1997), which most likely attributable to the turmoil in the aftermath of the financial crisis, with significant changes in interest rate environment. The monthly risk premium of 0.47% implies an average annual premium of over 5%. In contrast, the risk premium for changes in the probability of default $DEF$ is statistically not different from zero and even shows a negative sign. The negative sign can be well explained by the severe effects of the sovereign debt crisis and subsequent interest rate reductions on the European government bonds market, thus disordering the relationship between the returns on corporate bonds and government bonds. However, $DEF$ may help to explain the variation of returns in a time-series setting, due to its comparably high standard deviation of 1.53%. The same holds true for $TERM$, with a standard deviation of 2.11%.

The correlations between the explanatory variables are also presented in the lower section of Panel B. The correlation coefficients for the three systematic stock risk factors are low on average, which is attributable to the construction of the variables. The bond market risk factors, however, show a negative correlation coefficient -0.51, which is in line with previous studies. Nonetheless, all correlation figures are within the range of previous studies and are not high enough to cause serious multicollinearity issues.

### 4.5.2 Time Series Results

The results of the Fama-French (1993) three-factor model are presented in Table 3 below. [3] The intercept terms and factor loadings of the six infrastructure test portfolios for the relevant risk factors are shown in columns. Moreover, the adjusted $R^2$ and GRS F-statistic are at the bottom of the table. The t-statistics are adjusted for heteroskedasticity and serial correlation, if necessary, using White (1980) or Newey West (1987) standard errors.

In general, it is evident that all excess returns of the six infrastructure test portfolios reveal a significant loading on the stock market risk factors in the regressions, except for $HML$ in the case of small infrastructure companies with low BE/ME ratios (S/L). Hence, infrastructure stocks are strongly linked to developments in the general stock markets. In particular, the factor loadings on the market risk premium reveal that market excess returns are a highly significant driver of infrastructure stocks, since every factor loading is statistically significantly different from zero at the 1% level. In addition, the factor loadings are well below 1.0, emphasizing the defensive investment characteristics of infrastructure investments, due to relatively low market risk exposure. This result confirms the general hypothesis that infrastructure investments should be relatively unaffected from economic cycles, due to the low elasticity of demand for key essential services. The findings are in line with Rothballer and Kaserer (2012) and Ammar and Eling (2015), who find similar betas in their studies. Lastly, it is also obvious that small infrastructure companies tend to be less exposed to markets risk than large infrastructure companies, as they have slightly lower loadings on the market risk premium on average.

Concerning the factor loadings on size risk premium ($SMB$), it is evident that infrastructure companies follow the common pattern of positive loadings for small companies and negative loadings for large companies. This result confirms the general stock market size effect for infrastructure companies, and further emphasizes that the listed European infrastructure universe not only covers large cap stocks, as often indicated. As already shown in the descriptive statistics, small cap infrastructure companies are also listed in European capital markets that are mostly omitted from comparable analyses due to data issues or the use of index data. In addition, the size effect is stronger for small infrastructure companies in absolute terms. Whereas small infrastructure companies exhibit a positive factor loading of 0.33 on average, large firms only yield mean factor loadings of approximately -0.18. Corresponding, all three estimators for the small portfolios are statistically significantly different from zero at the 1% level, whereas this does not apply to the estimators of the large infrastructure portfolios.

Bird *et al.* (2014) find a positive relationship between infrastructure index returns and $HML$. Therefore, they conclude that infrastructure stocks are value stocks rather than growth stocks due to the fixed, large underlying asset base with limited growth opportunities. The results of our study back this finding only partly, since large companies with medium and low BE/ME ratios (B/M and B/L) have a negative loading on $HML$. However, four out of six coefficients show a positive sign (albeit only three are significantly positive), suggesting that infrastructure stocks tend to be value stocks. Nevertheless, no definite conclusion can be drawn based on these results. Generally, the value risk premium loads five out of six times significantly and can therefore be regarded as a persistent risk factor explaining the excess returns of European infrastructure stocks.

**Table 3: Time-series regression results on six infrastructure test portfolios for stock market risk factors**

| | Infrastructure Portfolios | | | | | |
|---|---|---|---|---|---|---|
| | S/H | S/M | S/L | B/H | B/M | B/L |
| *Stock Market Risk Factors* | | | | | | |
| Intercept | 0.003** | 0.001 | -0.002 | 0.005** | 0.006*** | 0.005*** |
| | (1.99) | (0.71) | (-1.35) | (2.55) | (3.27) | (2.67) |
| $R_M$ - $R_f$ | 0.359*** | 0.453*** | 0.456*** | 0.509*** | 0.531*** | 0.553*** |
| | (13.62) | (8.87) | (9.55) | (13.09) | (13.95) | (15.60) |
| SMB | 0.335*** | 0.354*** | 0.291*** | -0.215** | -0.149* | -0.174** |
| | (5.89) | (4.74) | (4.06) | (-2.56) | (-1.81) | (-2.28) |
| HML | 0.222*** | 0.107** | 0.059 | 0.166** | -0.134* | -0.407*** |
| | (4.19) | (2.03) | (0.91) | (2.12) | (-1.75) | (-5.70) |
| Observations | 264 | 264 | 264 | 264 | 264 | 264 |
| F-Statistic | 81.31 | 26.83 | 36.97 | 71.99 | 70.14 | 90.03 |
| Adjusted $R^2$ | 0.48 | 0.52 | 0.51 | 0.45 | 0.44 | 0.50 |
| GRS | 3.54 | | | | | |
| p(GRS) | 0.002 | | | | | |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model for the six infrastructure test portfolios; the regression is run for the period July 1992 ($m$=1) to June 2014 ($m$=264); $t$-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors; GRS is the $F$-statistic of Gibbons et al. (1989); p(GRS) is the p-value of GRS and is reported in the last row of the table.

As indicated in the methodology section, a good asset pricing model should be able capture most of the variation in excess returns and hence exhibit insignificant intercept terms and high adjusted $R^2$ in the test regressions. However, with respect to the intercept terms, four out of six are significantly positive. For instance, large companies with high BE/ME ratios (B/H) deliver high risk-adjusted monthly excess returns of 0.5%. On an annual basis, this would result in a notable risk-adjusted performance of approximately 6%. Accordingly, the GRS F-statistic strongly rejects the null hypothesis of all intercepts being jointly equal to zero at the 1% level, which emphasizes the limited goodness of the present asset pricing model. In addition, the adjusted $R^2$ amounts to 0.48 on average, which means that less than 50% of the total variation in infrastructure excess returns can be explained by the three-factor model. This result clearly suggests additional risk factors are missing in the present asset pricing models. For this reason, we additionally include two common bond risk factors, namely $TERM$ and $DEF$, in the asset pricing model. These results are presented in Table 4 below.

With respect to the factor loadings on the market risk premium and value risk premium, no noticeable differences in comparison to the three-factor model can be observed, as the slopes and significance levels do not alter substantially. In addition, small infrastructure companies still tend to be less exposed to market risks than large ones. The results for $HML$ are moreover virtually unaffected. However, by including the bond risk market factors in the asset pricing model, the weak significance levels of the coefficients for the large infrastructure test portfolios decline and no statistically significant size effect can be observed anymore.

**Table 4: Time-series regression results on six infrastructure test portfolios for stock market and bond market risk factors**

| | Infrastructure Portfolios | | | | | |
|---|---|---|---|---|---|---|
| | S/H | S/M | S/L | B/H | B/M | B/L |
| *Stock Market and Bond Market Risk Factors* | | | | | | |
| Intercept | 0.002 | 0.000 | -0.003 | 0.003 | 0.004** | 0.003* |
| | (1.50) | (0.28) | (-1.57) | (1.51) | (2.37) | (1.86) |
| $R_M$ - $R_f$ | 0.394*** | 0.476*** | 0.469*** | 0.572*** | 0.581*** | 0.609*** |
| | (14.48) | (12.57) | (10.62) | (14.65) | (15.12) | (16.14) |
| SMB | 0.390*** | 0.394*** | 0.316*** | -0.11 | -0.058 | -0.079 |
| | (6.84) | (5.97) | (4.68) | (-1.35) | (-0.73) | (-0.92) |
| HML | 0.232*** | 0.113* | 0.062 | 0.182** | -0.122* | -0.392*** |
| | (4.49) | (1.93) | (0.94) | (2.46) | (-1.67) | (-4.31) |
| TERM | 0.050 | 0.096 | 0.084 | 0.197** | 0.258*** | 0.202** |
| | (0.72) | (1.08) | (0.91) | (1.97) | (2.62) | (2.18) |
| DEF | -0.320*** | -0.189 | -0.093 | -0.528*** | -0.380*** | -0.462*** |
| | (-3.13) | (-1.27) | (-0.58) | (-3.60) | (-2.63) | (-3.24) |
| Observations | 264 | 264 | 264 | 264 | 264 | 264 |
| F-Statistic | 54.84 | 32.97 | 27.56 | 54.42 | 51.61 | 58.79 |
| Adjusted $R^2$ | 0.51 | 0.54 | 0.51 | 0.50 | 0.49 | 0.56 |
| GRS | 2.62 | | | | | |
| p(GRS) | 0.018 | | | | | |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for the six infrastructure test portfolios; the regression is run for the period July 1992 ($m$=1) to June 2014 ($m$=264); $t$-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors; GRS is the $F$-statistic of Gibbons et al. (1989); p(GRS) is the p-value of GRS and is reported in the last row of the table.

More importantly, the two bond risk market factors prove to be significant drivers of European infrastructure stock returns. There is an interesting pattern observable for $TERM$, since only large companies are affected by sudden changes in the interest rate environment. Only the three test portfolios with large companies (B/H, B/M, B/L) show a highly significant positive loading on the term premium of approximately 0.2-0.25. These figures are in line with those of Ammar and Eling (2015). Hence, large infrastructure companies are positively sensitive to interest rate changes. As interest rate changes are also a good proxy for sudden shocks in discount-rates (Fama and French, 1989), this result is not unexpected. Large infrastructure companies typically own a large and illiquid underlying asset base, which is highly exposed to valuation effects. As a result, investors seem to price this valuation exposure and require higher returns, because the asset valuation typically declines with higher discount rates. O'Neal (1998), for instance, also finds large utilities to be more sensitive to interest rates than small ones.

With regard to the factor loadings on the default premium, all coefficients show a negative sign. In addition, again, only the large test portfolios (and also one small test portfolio) reveal a statistically significant exposure to the additional bond risk factor. This fact might be explained by the comparably constrained access to bond markets for smaller listed firms. What is really striking about the factor loading is the unexpected negative sign. Generally, one would expect a positive factor loading, especially for infrastructure companies. Since these companies are typically highly levered, they should be exposed to changes in the debt markets. In addition, our findings contradict those of Ammar and Eling (2015), who find a positive factor loading on the default risk premium for U.S. infrastructure stocks. However, we argue that our deviating results can be explained by the underlying credit quality of infrastructure loans in European markets. According to a study of Moody's (2012), loans in the infrastructure and telecommunications segment show by far the lowest default rates. Moreover, default rates of Western, as well as Eastern European loans, are substantially lower than those of North American in the years 1983-2010. Therefore, the negative factor loading suggests that investors expect lower returns from infrastructure companies in times of increasing probability of default in the credit markets, due to the underlying credit quality. Nevertheless, it is crucial that the average monthly default risk premium is virtually zero. As a result, the economic significance is rather negligible. Nonetheless, DEF helps to explain the variation of infrastructure stocks in a time-series setting.

In contrast to the results for the Fama and French (1993) three-factor model, only two intercept terms are still significantly positive. This clearly shows that the inclusion of the two bond risk factors enhances the goodness of the asset pricing model. Correspondingly, the GRS F-statistic decreases approximately by 25% from 3.54 to 2.62. As a result, the null hypothesis of all intercepts being jointly equal to zero is now rejected only at the 5% level. Furthermore, the adjusted $R^2$ of the six test regression are on average approximately 5% higher than for the three-factor model. Hence, the augmented asst pricing model is capable of explaining approximately 52% of the total variance in infrastructure returns. While Fama and French (1993) find no additional explanatory power of bond risk factors for common stocks, this results hints at the peculiarity of infrastructure investments. Consistent with the bond risk factor loadings, the explanatory power of the test regressions for large infrastructure portfolios improves more than for small infrastructure portfolios.

To test the robustness of our results and to gain a greater insight into the pricing of infrastructure companies, particularly into the influence of the bond risk factors, we slightly modify the asset pricing model. Specifically, we first run the test regressions excluding the Global Financial Crisis (GFC) in order to test potential distortion in our results. Second, we estimate the factor loadings both for up- and down-markets. Lastly, we sort the infrastructure stocks into three test portfolios, according to their primary industry sector, to accentuate differences within subsectors of the infrastructure universe.

The results for the test regressions excluding the GFC, i.e. the period from August 2007 to June 2009, are presented in Appendix 1. In general, no significant deviation of the prior results can be observed for the factor loadings, thus emphasizing the robustness of our results towards possible distortions in the course of the GFC. However, it is obvious that the explanatory power of the models decreases, since the adjusted $R^2$ is on average below 45%. Obviously, the return behavior during distressed phases and economic downturns decisively influences the model quality. Accordingly, the asset pricing model should yield better results in down-markets as opposed to up-markets. Hence, we run a conditional specification of the augmented asset pricing model, separately for both phases of economic upswing and downswing. In accordance with Pettengill *et al.* (1995), bull markets are defined as phases with positive market excess returns and bear markets by negative market excess returns. In total, the sample is split into 148 months of up-markets and 93 months of down-markets. The corresponding results are displayed in Panel A (up-markets) and Panel B (down-markets) in Table 5.

**Table 5: Conditional time-series regression results on six test portfolios for stock market risk factors and bond risk factors**

| | Infrastructure Portfolios | | | | | |
|---|---|---|---|---|---|---|
| | S/H | S/M | S/L | B/H | B/M | B/L |
| *Panel A: Stock Market and Bond Market Risk Factors - Up Markets* | | | | | | |
| Intercept | 0.011*** | 0.001 | 0.003 | 0.008** | 0.011** | 0.008** |
| | (4.52) | (0.34) | (1.07) | (2.24) | (2.85) | (2.55) |
| $R_M$ - $R_f$ | 0.230*** | 0.418*** | 0.311*** | 0.480*** | 0.424*** | 0.498*** |
| | (4.46) | (4.20) | (3.75) | (6.04) | (4.99) | (5.73) |
| SMB | 0.404*** | 0.400*** | 0.254*** | -0.112 | -0.066 | -0.040 |
| | (5.79) | (3.99) | (3.18) | (-1.04) | (-0.57) | (-0.33) |
| HML | 0.184*** | 0.171* | 0.007 | 0.182* | -0.091 | -0.390** |
| | (2.76) | (1.80) | (0.07) | (1.77) | (-0.83) | (-2.44) |
| TERM | 0.022 | 0.212** | 0.125 | 0.199 | 0.284*** | 0.250* |
| | (0.26) | (2.28) | (1.31) | (1.54) | (2.04) | (1.73) |
| DEF | -0.322** | -0.218 | -0.004 | -0.689*** | -0.450*** | -0.521** |
| | (-2.56) | (-1.60) | (-0.03) | (-3.55) | (-2.17) | (-2.47) |
| Observations | 148 | 148 | 148 | 148 | 148 | 148 |
| F-Statistic | 12.16 | 6.97 | 4.99 | 13.87 | 8.24 | 10.87 |
| Adjusted $R^2$ | 0.26 | 0.32 | 0.17 | 0.29 | 0.19 | 0.30 |
| *Panel B: Stock Market and Bond Market Risk Factors - Down Markets* | | | | | | |
| Intercept | -0.002 | 0.007* | 0.003 | 0.002 | 0.006 | 0.003 |
| | (-0.56) | (1.93) | (0.94) | (0.35) | (1.42) | (0.70) |
| $R_M$ - $R_f$ | 0.375*** | 0.571*** | 0.617*** | 0.547*** | 0.631*** | 0.616*** |
| | (6.03) | (9.13) | (7.03) | (5.60) | (8.38) | (8.20) |
| SMB | 0.376*** | 0.339*** | 0.370*** | -0.134 | -0.093 | -0.145 |
| | (3.97) | (3.55) | (3.82) | (-1.09) | (-0.81) | (-1.27) |
| HML | 0.277*** | 0.042 | 0.124 | 0.136 | -0.159 | -0.413*** |
| | (3.40) | (0.51) | (1.16) | (1.45) | (-1.61) | (-4.19) |
| TERM | 0.095 | -0.061 | 0.029 | 0.181 | 0.214 | 0.142 |
| | (0.83) | (-0.53) | (0.20) | (0.99) | (1.54) | (1.02) |
| DEF | -0.272 | -0.154 | -0.239 | -0.319 | -0.273 | -0.352* |
| | (-1.62) | (-0.91) | (-0.85) | (-1.00) | (-1.34) | (-3.57) |
| Observations | 93 | 93 | 93 | 93 | 93 | 93 |
| F-Statistic | 12.67 | 20.92 | 12.85 | 7.27 | 15.56 | 16.75 |
| Adjusted $R^2$ | 0.36 | 0.49 | 0.48 | 0.31 | 0.41 | 0.43 |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for the six infrastructure test portfolios; the regression is run for the period July 1992 ($m$=1) to June 2014 ($m$=264); $t$-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors.

As expected, the explanatory power of the asset pricing model during phases of downswing is incrementally higher than for phases of upswing. Additionally, only one, instead of four intercept terms, are statistically significant in the asset pricing model in Panel B. With respect to the stock risk factors, the results are in broad agreement with the prior results, albeit the two significant factor loadings on $HML$ vanish in down-markets. Interestingly, the betas in up- markets are substantially lower than in down-markets. This might be explained by the specific revenue schemes of infrastructure companies, which will be discussed further in the next section. The most interesting observation is the fact that the connection to bond markets is almost only present during up-markets. During down-markets, only one statistically significant factor loading on DEF can be identified. Hence, infrastructure companies are apparently only interest rate sensitive during phases of economic recovery. As phases of economic recovery are typically accompanied by subsequent rising interest rates, investors might demand higher returns from infrastructure firms, in order to compensate for the risk of future depreciation of the underlying asset base due to increasing discount rates. In contrast, phases of financial distress lead rather to falling interest rates, thus stimulating underlying asset values. Hence, investors do not perceive the connection to the bond markets as a risk factor in a narrower sense. To verify the results with respect to the bond risk factors, we also run the regression models for one single infrastructure portfolio without taking into account the portfolio formation process, i.e. we construct one portfolio containing all infrastructure stocks. In addition, we calculate both, equally-weighted as well as value-weighted portfolio returns. The regression outputs are presented in Appendix 2 and 3 and yield qualitatively the same results, thus underlining the robustness of our prior results.

Ultimately, the results for the three test portfolios, sorted by different infrastructure subsectors, are presented in Table 6 below. With respect to the intercept terms, transport companies have outperformed the other sectors by far. Generally, all three subsectors show a high monthly risk-adjusted performance of 0.3%-0.6%. Concerning the market risk premium, transportation companies yield a higher beta than telecommunication firms and utilities. This is most likely due to the strong link between the general economic situation and the resulting traffic volume, which in turn decisively influences revenue from transportation companies. The loadings on $SMB$ suggest that, on average, all European infrastructure sectors predominantly behave like small companies, which resembles the results for the six infrastructure test portfolios with respect to the diversity in significance levels. Likewise, telecommunication firms and utilities can be regarded as value stocks, whereas transport firms tend to behave like growth stocks. In terms of the sensitivity towards bond risk factors, the term premium is only priced for utilities, which is in line with O'Neal (1998). Hence, the general interest rate sensitivity can be attributed mainly to the utilities sector. In addition, only utilities and transportation companies reveal a significant relationship with the default premium. This could be explained by the underlying asset structure of transportation companies and utilities, which might be better suited for debt capital markets. This hypothesis is backed by the information provided by Moody's (2012). According to the study, telecommunication companies only account for 9.3% of all project loans, whereas other infrastructure sectors account for almost 75%. In addition, telecommunication utilities appear to exhibit leverage ratios under 40% (Cambini and Rondi, 2012), whereas the overall mean average ratio of infrastructure companies generally exceeds 55% (MSCI, 2015), emphasizing the comparably lower exposure to debt capital markets.

**Table 6: Time-series regression results on six test portfolios for stock market risk factors and bond risk factors – Subsectors**

| | Infrastructure Portfolios | | |
|---|---|---|---|
| | Transport | Telecom | Utilities |
| *Stock Market and Bond Market Risk Factors - Subsectors* | | | |
| Intercept | 0.006*** | 0.003*** | 0.004*** |
| | (3.36) | (2.05) | (3.20) |
| $R_M$ - $R_f$ | 0.704*** | 0.448*** | 0.435*** |
| | (17.89) | (16.91) | (13.88) |
| SMB | 0.163** | 0.352*** | 0.183*** |
| | (1.98) | (6.32) | (3.56) |
| HML | -0.487*** | 0.179*** | 0.238*** |
| | (-6.51) | (3.56) | (4.13) |
| TERM | 0.089 | 0.067 | 0.173** |
| | (0.88) | (0.99) | (2.16) |
| DEF | -0.476*** | -0.139 | -0.264** |
| | (-3.22) | (-1.39) | (-2.28) |
| Observations | 264 | 264 | 264 |
| F-Statistic | 68.05 | 71.40 | 54.30 |
| Adjusted $R^2$ | 0.56 | 0.57 | 0.58 |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for three industry portfolios; the regression is run for the period July 1992 ($m$=1) to June 2014 ($m$=264); $t$-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors.

### 4.5.3 Discussion

The results presented in the previous section allow for two different interpretations. On the one hand, one might argue that the (statistically significant) positive intercept terms in the five-factor regressions attest to a high risk-adjusted performance for infrastructure companies in general. This interpretation would only be correct if we assume that the five-factor model, including all common risk factors, represents the correct return-generating process of infrastructure returns.

However, we argue that even the five-factor model is not capable of sufficiently explaining the variation in infrastructure stock returns. We attribute this mainly to the relatively low explanatory power of only approximately 55% on average. Comparable European asset pricing studies in the real estate field, for instance, find adjusted $R^2$ of well above 70% (Scholz, Lang and Schaefers, 2014), using only the Fama and French (1993) three-factor model. Our argument is further backed by Fama and French (1997) and Chou, Ho and Ko (2012), who find that industry returns generally cannot be explained fully by the common asset pricing models. Additionally, we also explain our results with two specific attributes and investment characteristics of infrastructure investments.

First, the limited suitability of conventional asset pricing models for infrastructure stock returns might be due to the specific underlying revenue schemes of infrastructure firms. How infrastructure returns are generated is quite distinct from other industries. As most infrastructure investments are typically regulated in some way (e.g. via price cap regulation) the upside potential of an infrastructure company's revenue is limited. For instance, utilities are (mostly) monopolies and therefore controlled by a government-appointed regulator. During formal processes, utilities negotiate the rate they are allowed to charge customers for their services, or the appropriate return on equity they are allowed to earn. As a result, the upside potential is limited, while the downside potential is not. This argument might be indirectly reflected by the findings of higher betas during down-markets, compared to those during up-markets. Infrastructure firms may not be able to fully unfold the potential of the general stock markets during upswings, due to price cap regulations. Furthermore, the explanatory power of the asset pricing models has proven to be markedly better in times of economic downswing. Correspondingly, the distribution of infrastructure stocks would rather be skewed to the left. With regard to the descriptive statistics, all six infrastructure test portfolios prove to be skewed to the left, thus underlining this point. However, no empirical evidence supporting this argumentation is yet available, thus requiring further investigation. In addition, left-skewed return distributions also exhibit fat left tails, indicating a high level of unsystematic risk, which is the second infrastructure-specific attribute that might explain the results.

The relatively low explanatory power of only 55% on average implies a high level of idiosyncratic risk for infrastructure companies. As already presented in the literature review, Rödel and Rothballer (2012) confirm this argumentation empirically. Generally, infrastructure companies face several specific risks that may explain the high proportion of unsystematic risk. One important risk driver is the low level of product and geographic diversification of infrastructure firms, thus making them reliant on the specific business model and location. Therefore, infrastructure companies often face long-term concentrated counterparty risk compared to other industries. As a result, infrastructure companies are also particularly exposed to certain external event risks, such as political and regulatory changes. A prominent example is the decision of the German government to phase out nuclear power earlier than planned, due to the serious accident in Fukushima. Additionally, asset and project-specific risks further cause high idiosyncratic risks, especially construction risks. Cost overruns and delays of new infrastructure projects have severe impacts on the involved infrastructure firms. Likewise, financial risks due to high operating leverage occur if sales decline or technology progresses substantially, such as in the case of fixed-line networks. Again, the long duration of the specific and location-bound asset base prevents infrastructure firms from adapting accordingly (Rödel and Rothballer, 2012, Partners Group, 2012). Given these examples, it may not surprise that the six infrastructure test portfolios still exhibit idiosyncratic risks, despite the sufficiently high number of test assets in each portfolio. Even in the case of three industry test portfolios with a larger number of constituents, the explanatory power of the regression models did not increase substantially.

All in all, another obvious solution would be to include a further (systematic) risk factor that is still missing in the model, and that might therefore help to increase the goodness of fit. Therefore, we also tested for further risk factors in our asset pricing model. Nevertheless, the empirical results did not alter and the augmented models were not able to explain markedly more variance in infrastructure returns. Specifically, we tested the well-known Carhart (1997) momentum factor and found almost no significant factor loadings. Furthermore, we included an additional leverage risk factor, as suggested by Ammar and Eling (2015). However, the inclusion raised justified concerns of multicollinearity, since the leverage factor had a substantial influence on the $HML$-loadings. This shows that the leverage effect is already indirectly reflected in the value-factor. Ultimately, we also tested a liquidity risk factor, as suggested by Scholz *et al*. (2014), which has proven to drive the returns of European listed real estate companies. Again, we could not find significant factor loadings. [4]

To sum up, there is still a lot of potential in the field of infrastructure asset pricing. Most likely, another systematic or infrastructure specific risk factor is still to be discovered. As previously suggest by Bird *et al.* (2014), a regulatory risk factor might be part of the solution, given the importance of regulation in infrastructure markets However, no such risk factor has yet been developed and the construction for a cross-European factor might cause severe problems, due to the different regulatory regimes prevailing. With regard to the general finance literature, recent empirical evidence from Chen, Novy-Marx and Zhang (2011) suggests that alternative risk factors are in favor of the traditional risk-factors in U.S. markets. Although Walkshaeusl and Lobe (2014) could not confirm these findings for international stock markets, the alternative factors might be able to better explain the returns of infrastructure firms. These alternative factors (namely profitability and investment factor) explain the expected returns from a production perspective, instead of a consumer perspective. As the infrastructure business per-se is highly investment-intensive, a high sensitivity of expected returns should be observable. Future research should therefore compare and/or combine both asset pricing models.

## 4.6. Conclusion

The present study investigates the pricing of infrastructure equity returns using conventional asset pricing models with common risk factors. The underlying infrastructure equity data set is unique in its composition, due to the intensive screening progress. Hence, this study is the first to investigate the pricing of all European infrastructure equities that own and/or operate physical infrastructure. The results suggest that the well-known Fama and French (1993) three-factor model is unable to capture most of the variation in infrastructure equity returns, although all stock risk factors reveal a significant influence on the excess returns of infrastructure companies. After accounting for risk factors related to market, size and BE/ME, all intercepts are still jointly different from zero.

Given the supposedly tight connection of infrastructure firms to bond markets, we also include common bond risk factors, so as to investigate the particular influence on infrastructure returns. The goodness of the asset pricing model increases markedly, when adding two additional bond risk factors, namely term and default premium. We show that large infrastructure companies are sensitive to interest rate movements, especially during up-markets. When accounting for different sub-sectors within the infrastructure industry, the results reveal that most of the interest rate sensitivity can be attributed to utilities, rather than transportation or telecommunication. However, even the augmented asset pricing model is not sufficient to explain the excess returns of infrastructure firms. Hence, we conclude that this is mainly due to specific infrastructure investment characteristics. Firstly, infrastructure returns are typically regulatorily capped, so that the return distribution is somehow different from general stocks, which might hinder the application of traditional pricing models. Secondly, infrastructure companies are particularly exposed to a high level of idiosyncratic risk, hence leaving a substantial part of the variance unexplained.

The results should be very helpful for investors and portfolio managers, whose aim is to construct a diversified portfolio, as the factor loadings help to evaluate the exposure to stock market risk factors. More importantly, the results show that bond risk factors need to be accounted for in asset pricing models, in order to derive the cost of capital more precisely. Nevertheless, investors need to be aware that not all variance can be explained by the risk factors, so that part of the raw returns cannot be attributed to specific risk factors. Hence, outperformance of infrastructure stocks might be only a compensation for taking unknown risks. Besides investors, the results are also of great interest for policy makers, especially in the light of increasing privatizations and PPPs. The asset pricing models can help to evaluate PPPs in a more meaningful manner. The Australian government, for instance, employs the concepts of the Capital Asset Pricing Model (CAPM) in order to financially evaluate PPPs.

Ultimately, this paper provides researchers with various avenues for further research. First of all, as already mentioned in the previous section, alternative risk factors might be included in the framework. This first study deliberately employs the most widely-used asset pricing as a starting point. However, the results show that the common risk factors only tell a part of the story. Accordingly, further risk factors could be constructed, above all, a regulatory risk factor. It would be of further interest to compare across different European countries, as soon as more country-specific data is available. Most importantly, the pricing of unlisted infrastructure investments remains to be explained, including to what extent common risk factors might help to predict unlisted infrastructure returns. The recent launch of MCSI's World Core Infrastructure Index for unlisted infrastructure vehicles might constitute a valid starting point in the near future.

## 4.7 ENDNOTES

[1] Source: www.privatizationbarometer.net; retrieved on July 5, 2015.

[2] We deem this approximation as sufficient for our research purposes. Firstly, other asset pricing studies with a European context have used U.S. data in order to derive the default premium (e.g. Bauer, Cosemans and Schotman, 2010). Secondly, the two bond risk indices yield comparable descriptive statistics and high correlation.

[3] Prior to running the Fama-French (1993) three-factor model, we also tested the traditional Capital Asset Pricing Model (CAPM) and found comparably high explanatory power. However, the three-factor model is in favor of the CAPM, both in terms of the adjusted $R^2$ and the GRS-F statistics. Hence, we do not report these results.

[4] For reasons of brevity, these results are not reported.

## 4.8 Appendix

**Appendix 1: Time-series regression results on six infrastructure test portfolios for stock market risk factors and bond risk factors excluding financial crisis and sovereign debt crisis**

| | Infrastructure Portfolios | | | | | |
|---|---|---|---|---|---|---|
| | S/H | S/M | S/L | B/H | B/M | B/L |
| *Stock Market and Bond Market Risk Factors - excluding Financial Crisis* | | | | | | |
| Intercept | 0.002 | 0.002 | -0.001 | 0.004 | 0.005** | 0.004** |
| | (1.41) | (1.29) | (-0.62) | (1.96) | (2.48) | (2.16) |
| $R_M$ - $R_f$ | 0.390*** | 0.406*** | 0.380*** | 0.553*** | 0.557*** | 0.607*** |
| | (12.30) | (10.80) | (9.82) | (12.73) | (12.73) | (13.47) |
| SMB | 0.381*** | 0.307*** | 0.237*** | -0.133 | -0.072 | -0.078 |
| | (6.21) | (4.48) | (3.63) | (-1.58) | (-0.85) | (-0.85) |
| HML | 0.244*** | 0.094* | 0.079 | 0.199*** | -0.121 | -0.401*** |
| | (4.52) | (1.76) | (1.20) | (2.69) | (-1.62) | (-4.25) |
| TERM | 0.049 | 0.056 | 0.011 | 0.199** | 0.279*** | 0.179* |
| | (0.66) | (0.78) | (0.14) | (2.69) | (2.68) | (1.84) |
| DEF | -0.373*** | -0.312 | -0.266 | -0.706*** | -0.473*** | -0.558*** |
| | (-3.36) | (-2.23) | (-2.04) | (-4.64) | (-3.08) | (-3.57) |
| Observations | 241 | 241 | 241 | 241 | 241 | 241 |
| F-Statistic | 37.87 | 24.78 | 22.93 | 44.61 | 38.96 | 42.36 |
| Adjusted $R^2$ | 0.43 | 0.41 | 0.37 | 0.48 | 0.44 | 0.53 |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for the six infrastructure test portfolios; the regression is run for the period July 1992 ($m$=1) to June 2014 ($m$=264), excluding the period from August 2007 to June 2009; $t$-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors.

**Appendix 2: Time-series regression results on equally-weighted infrastructure test portfolio for stock market risk factors and bond risk factors**

| | All Infrastructure Stocks - equally-weighted | | | | |
|---|---|---|---|---|---|
| | | | *ex-GFC* | *Up Markets* | *Down Markets* |
| Intercept | 0.003** | 0.002* | 0.003** | 0.007*** | 0.003 |
| | (2.31) | (1.68) | (2.30) | (2.73) | (1.18) |
| $R_M$ - $R_f$ | 0.477*** | 0.512*** | 0.482*** | 0.393*** | 0.560*** |
| | (14.68) | (19.21) | (15.96) | (5.47) | (12.47) |
| SMB | 0.074 | 0.143 | 0.107** | *0.14* | 0.119* |
| | (1.39) | (2.90) | (2.23) | (1.81) | (1.67) |
| HML | 0.002 | 0.013 | 0.016 | 0.01 | 0.007 |
| | (0.04) | (0.24) | (0.26) | (0.12) | (0.10) |
| TERM | | 0.148** | 0.129** | 0.182** | 0.100 |
| | | (2.27) | (1.97) | (2.07) | (1.00) |
| DEF | | -0.330*** | -0.448*** | -0.367*** | -0.268 |
| | | (-2.69) | (-3.92) | (-2.82) | (-1.39) |
| Observations | 264 | 264 | 241 | 148 | 93 |
| F-Statistic | 120.45 | 87.00 | 61.64 | 15.04 | 20.72 |
| Adjusted $R^2$ | 0.58 | 0.63 | 0.57 | 0.33 | 0.51 |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for the equally-weighted infrastructure test portfolio; *t*-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors.

**Appendix 3: Time-series regression results on value-weighted infrastructure test portfolio for stock market risk factors and bond risk factors**

| | All Infrastructure Stocks - value-weighted | | | | |
|---|---|---|---|---|---|
| | | | *ex-GFC* | *Up Markets* | *Down Markets* |
| Intercept | 0.008*** | 0.007*** | 0.007*** | 0.0118*** | 0.005 |
| | (4.19) | (4.12) | (4.16) | (3.46) | (1.29) |
| $R_M - R_f$ | 0.558*** | 0.622*** | 0.620*** | 0.532*** | 0.560*** |
| | (15.06) | (18.11) | (15.22) | (5.01) | (9.79) |
| SMB | -0.292*** | -0.184* | -0.178 | -0.121 | -0.260* |
| | (-2.83) | (-1.78) | (-1.58) | (-0.78) | (-1.84) |
| HML | -0.269* | -0.251* | -0.259* | -0.296 | -0.236*** |
| | (-1.88) | (-1.95) | (-1.92) | (-1.28) | (-2.71) |
| TERM | | 0.185* | 0.211** | 0.250* | 0.112 |
| | | (1.78) | (2.08) | (1.74) | (0.77) |
| DEF | | -0.554*** | -0.632*** | -0.618*** | -0.434** |
| | | (-3.84) | (-4.18) | (-3.07) | (-2.17) |
| Observations | 264 | 264 | 241 | 148 | 93 |
| F-Statistic | 80.76 | 61.04 | 50.31 | 13.90 | 13.39 |
| Adjusted $R^2$ | 0.48 | 0.54 | 0.52 | 0.31 | 0.40 |

Notes: *, ** and *** denote coefficients with statistical significance at 10, 5 and 1 percent levels; this table reports the time-series regression results for the Fama and French three-factor model augmented by two bond risk factors for the value-weighted infrastructure test portfolio; *t*-statistics are in parentheses and, if necessary, adjusted for heteroskedasticity and serial correlation using White (1980) HC3 or Newey-West (1987) standard errors.

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# 5 Conclusion

The following section presents the executive summaries for all three articles of the dissertation at hand with regard to the motivation, data and methodology as well as key results. Furthermore, the dissertation concludes with final remarks on the general research topic and maps out future avenues for research in the field of infrastructure investments.

## 5.1 Executive Summary

**Inflation Hedging and Protection Characteristics of**

**Infrastructure and Real Estate Assets**

The first paper investigates the short-term and long-term inflation-hedging characteristics of direct and listed infrastructure investments. In addition, common direct and listed real estate indices are included in the study, so as to allow for a comparison between the two supposedly closely related asset classes. There is a common belief that both, infrastructure and real estate investments offer attractive inflation-hedging characteristics for investors, which stems from the fact that both assets are seen as real assets, and the corresponding cash flows are mostly contractually linked to inflation.

The study therefore opens with a detailed and comprehensive theoretical analysis of the influence of inflation on infrastructure assets. While most other studies make only general comments, this paper highlights the significance of a detailed sector-specific analysis. In general, the inflation-hedging capacity is dependent on the revenue-scheme (regulation by contract or agency), the pass-through mechanism of operating costs, the replacement value of existing assets and specific capital structure that might erode inflation-hedging. An extensive literature review on existing studies that concentrate on the relationship between infrastructure and inflation (e.g. Rödel and Rothballer, 2011) follows next. It is evident that only few studies to date focus on (direct) infrastructure and inflation, thus emphasizing the significance of the given study.

To empirically analyze the short-term and long-term relationship with inflation, the paper investigates the US market, based on quarterly total-return data spanning the period from Q1 1991 to Q1 2013. With help of a unique direct infrastructure performance index, provided by the Center of Private Equity Research (CEPRES), this is the first paper to answer this research question. The traditional Fama and Schwert (1977) methodology is used to assess the short-term inflation hedge, and Engle and Granger (1987) co-integration tests are conducted to analyze the relationship in the long-run. Furthermore, Granger causality tests allow for insights into the short-run dynamics. Ultimately, different shortfall risk measures are calculated to analyze the inflation protection characteristics in terms of a positive real return for different given investment holding periods.

The results suggest that direct infrastructure is the only asset exhibiting a (partial) short-term inflation hedge. In the long-run, all assets included in the study reveal a relationship with inflation. However, the causality tests indicate that inflation Granger-causes real estate, whereas infrastructure seems to Granger-cause inflation. Regarding the inflation protection, direct infrastructure investments offer the best inflation protection among all assets in the sample period. All in all, this paper provides some initial empirical evidence on a very relevant research gap and helps investors to evaluate the expected inflation-hedging characteristics of direct infrastructure investments.

### Solvency II and Portfolio Efficiency

### – The Case of Infrastructure and Real Estate Investment

The second paper of the present dissertation investigates the potential effects of the forthcoming Solvency II Directive on the portfolio efficiency and asset allocation of institutional investors. Specifically, the focus lies on the potential shift of real estate and infrastructure allocation within the mixed asset portfolio of a representative European insurance company. These alternative assets have been attracting more and more interest in the past few years, as investors seek high risk-adjusted returns in the current structural low interest rate environment. However, Solvency II introduces a new risk-based model for deriving the capital requirements of an insurer in dependency on the specific portfolio structure. As real estate and infrastructure assets are heavily penalized by the standard formula of the Solvency II Directive, the abovementioned development might well be hampered, as insurance companies may be forced to minimize the capital requirements by means of their asset allocation.

Accordingly, the paper starts with a brief and comprehensive description of the key concepts of the Directive that abstracts from the extensive legal sources. Hence, only the most important information with respect to the research focus (i.e. the calculation of market risk capital requirements) is outlined. In the following literature review, the most relevant (empirical) studies on the Solvency II Directive are presented (e.g. Braun *et al.*, 2013). It is obvious that hardly any studies have yet dealt with the portfolio effects on a meaningful basis. As this paper also contributes to the well-established research stream on the disparity between theoretical optimal weights and the actual portfolio weights observable in practice, a second section focuses on the relevant studies covering this area of research. Thus, this study enhances the literature in several ways.

The empirical study covers the period from Q1 1993 to Q4 2014, using European total return data retrieved from Thomson Reuters Datastream and conducts different portfolio optimizations with the following set of assets: direct real estate, direct infrastructure, government bonds, corporate bonds, stocks and money market instruments. The special feature of the study is the first use of a performance index for direct infrastructure investments in Europe, which is again provided by CEPRES. Firstly, Markotwitz (1952) portfolio optimizations are used to derive the efficient portfolio with respect to portfolio risk. Next, the empirical covariance matrix is replaced with the regulatory correlation matrix imposed by Solvency II, in order to calculate efficient portfolios with regard to capital requirements. Thirdly, both optimizations are blended, in order to derive optimal portfolios with respect to portfolio risk, given certain capital constraints.

The results reveal that, although there is evidence of an incorrect parameterization of the regulatory correlation matrix, Solvency II is unlikely to have a decisive impact on real estate and infrastructure portfolio allocation. Only insurance companies which are under-capitalized might be forced to reduce their exposure to alternative assets. Well-capitalized insurance companies, on the other hand, can still afford to allocate their funds to real estate and infrastructure assets and even potentially extend the quotas beyond their current asset allocation. This paper therefore fills a very relevant research gap and provides a new framework for assessing the potential effects of Solvency II at the portfolio level.

**Can Common Risk Factors Explain Infrastructure Equity Returns?**

**Evidence from European Capital Markets**

The third and final paper of this dissertation tests the ability of conventional asset pricing models to explain shared variation in the returns of listed infrastructure companies. While there is already a modest number of studies with a focus on the pricing of US and Australian infrastructure stocks (e.g. Bird *et al.*, 2014; Ammar and Eling, 2015), no study has yet examined the European market. This is surprising, given the fact that the European infrastructure market is by far the largest by volume and most active by number of deals.

The paper starts with a brief review of the empirical literature on related research issues. Generally, the literature on infrastructure asset pricing can be divided into two separate research streams. Whereas the one focuses on infrastructure sub-sectors, such as oil and gas companies, the second and more recent research stream focuses on infrastructure companies in general. These studies adopt the definition of economic infrastructure and subsume utilities, telecommunications and transportation firms. In line with this definition, the present paper builds on an individually created infrastructure equity data set, using an intensive screening process. In the course of this process, only those infrastructure companies that truly own and/or operate physical infrastructure remain in the final sample. In total, the data sample consists of 285 infrastructure companies located in 16 European countries.

The following empirical analysis covers the period from June 1992 to July 2014, thus yielding 264 monthly observations. The paper employs the widely-used Fama and French (1993) three-factor model, including the stock market risk factors related to market, size and BE/ME. The three-factor model is augmented by two additional bond market risk factors, namely term and default risk, since infrastructure companies might be strongly related to bond markets, given the relatively high leverage ratios. The results reveal that the three-factor model fails to sufficiently explain the excess returns, although all risk factors show significant factor loadings. However, the additional bond market factors enhance the model quality and prove to be further factors in pricing European infrastructure firms, even after taking the stock market risk factors into account. Hence, infrastructure stocks seem to be sensitive to changes in interest rates. Nevertheless, the results also suggest that further potential risk factors have not yet been identified. To sum up, this is the first paper to assess the pricing of listed European infrastructure companies and might therefore help investors to manage their risk exposure more efficiently. Not least, the results should help policy makers to improve their financial understanding of the asset class, which might in turn be beneficial for future privatizations and PPPs.

## 5.2 Final Remarks and Further Research

In summary, the three articles within this dissertation provide valuable empirical evidence on infrastructure-specific issues, thereby contributing to the emerging research stream on infrastructure investments within the general finance literature. It is shown that direct infrastructure indeed represents a good inflation-hedging asset and should therefore be acknowledged by institutional investors. Moreover, the thesis reveals that the common concerns of the infrastructure and real estate industry with regard to the introduction of Solvency II have become irrelevant. The results of the second paper underline that a significant shift or change in the investment patterns of institutional investors concerning real asset allocation should not be expected. Ultimately, this thesis also provides evidence on the listed infrastructure market and presents some first insights into the pricing of European listed infrastructure firms, illustrating a unique risk and return profile.

Nevertheless, the findings also raise further questions which could be accounted for in future research. First of all, the inflation-hedging attributes of infrastructure investments could be analyzed within a macro-economic framework, in order to analyze the relationship between infrastructure returns and the general economy. Moreover, recent studies link the inflation-hedging analysis to traditional asset allocation analysis, thus evaluating the relationship to inflation within the mixed asset portfolio of an investor.

With regard to the second paper, there are also comparable regulatory models for US insurance companies or pension plans, according to which the individual capital requirements have to be determined. The suggested methodology could easily be adapted as to extend the significance of the results to other types institutional investors or regions.

Ultimately, the third paper also opens up many avenues for further research. Most importantly, one could identify further risk factors that are infrastructure-specific and may therefore be able to explain most of the variation in returns. In addition, with help of the large infrastructure dataset, many other research questions could be handled. For instance, using the dividend payments of all European infrastructure firms as a proxy, one could examine whether infrastructure investments indeed deliver stable cash flows.

All in all, it is noticeable that the development of infrastructure research closely resembles the development of real estate research. Likewise, for real estate, no generally accepted benchmark for direct investments was available in the early years of real estate research. This dissertation was (in part) only accomplished, thanks to a novel dataset from the Center of Private Equity Research (CEPRES), which was the first to establish a performance index for direct infrastructure. However, this index is not freely available, thus limiting extensive academic use. In real estate research, among other reasons, the data quality has started to significantly improve with the establishment of acknowledged organizations and data providers, such as the National Council of Real Estate Investment Fiduciaries (NCREIF) or the Investment Property Databank (IPD), thus catalyzing independent real estate research. Interestingly, it is IPD (now part of MSCI) that has recently launched a global quarterly infrastructure index tracking the investment performance of direct infrastructure. Hence, this new index could represent a new starting point for academics and thereby a driving force for infrastructure research. Also, the empirical studies available to date could now be validated using an alternative data source. Nevertheless, given the heterogeneous nature of infrastructure, a crucial requirement for future infrastructure research is still the availability of sector-specific data, in order identify differences between the various infrastructure sectors. Concerning the research on listed infrastructure, it would be very helpful to establish organizations similar to the real estate industry, such as the National Association of Real Estate Investments Trusts (NAREIT) or the European Public Real Estate Association (EPRA), in order to bundle data and knowledge. Given the many different industry sectors involved in the infrastructure business, this is likely to take some time. However, ongoing research might expedite this development, and it is hoped that this dissertation makes its own contribution.

## 5.3 References

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