Paper 4: Direct Infrastructure Investment and its Role in Drawdown-Efficient Portfolios

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Abstract

This paper investigates the role of direct infrastructure in a multi-asset portfolio, by employing a US transaction-based index which covers the period Q2 1990 to Q2 2010. We use an algorithm which minimizes Conditional Drawdown at Risk (CDaR) to determine time-varying asset allocations. In addition to infrastructure, the asset menu comprises large and small cap stocks, bonds of different maturities and cash. Our results show that infrastructure plays an important role and is allocated predominantly to portfolios that exhibit low-to-medium risk exposure. We cannot find any evidence that infrastructure provides a hedge against pension liabilities, but it is a viable asset when various predefined target returns are the reference point for evaluating portfolio performance. We also find that infrastructure is a hedge against systematic equity-market downside risk and contributes to a portfolio which is designed to protect an investor against a decline in portfolio value when the equity market drops.

JEL classification: G10, G11, G15, G23, H54

Keywords: Infrastructure, Portfolio Management, Conditional Drawdown at Risk, Dynamic Asset Allocation

4.1 Introduction

During the last few years, direct infrastructure investments have moved into the focus of many institutional investors[1]. This private involvement is driven by financial strains on governments, which render the public sector unable to guarantee adequate infrastructure provision[2]. The imbalance between infrastructure provision and demand is expected to gain further momentum and increase privatization pressure over the long run. According to the OECD (2006, 2007), cumulative global infrastructure needs are estimated to rise to US$ 71 trillion by 2030, this is about four times the value of the current global infrastructure stock and includes the enormous requirements of developing countries.

Despite the heterogeneity of the infrastructure universe, investors are attracted by several major characteristics associated with the asset class. Firstly, due to their monopolistic nature, infrastructure investments are expected to provide stable and predictable cash flows which may enable investors to match their long-term liabilities. Secondly, as a result of this monopolistic character and the provision of basic services, cash flows from infrastructure investments are also assumed to be less vulnerable to economic downturns than other more cyclical assets. This could make them attractive to investors seeking new sources of diversification, in order to hedge their portfolios against downturns of traditional assets such as stocks and bonds. Studies from Newell and Peng (2008) as well as Dechant, Finkenzeller and Schaefers (2010) provide some empirical evidence of the benefits of including infrastructure in an investment portfolio. Thirdly, some specific infrastructure investments, such as alternative energies, are associated with the increasing significance of socially responsible investment strategies and the need for an enhanced public image.

The increasing attraction of infrastructure investments, along with its unique asset characteristics, have confirmed the role of infrastructure as separate asset class and large institutional investors have begun to establish specific allocation targets. Although the average allocation to infrastructure is not expected to exceed 2% on average globally (Croce, 2011; Inderst, 2010), large North American and Australian pension schemes already hold up to 15% of their total wealth in infrastructure .

[1] Infrastructure assets can be divided into two main categories of economic and social infrastructure. Economic infrastructure includes long-lasting, large-scale physical structures like transportation and communication infrastructure, as well as energy and utility facilities. Social infrastructure, on the other hand, includes education, healthcare, waste disposal, as well as judicial facilities (see, for example, Kaserer, Buchner, Schmidt and Krohmer, 2009). According to Mansour and Patel (2008), the entire global infrastructure universe is estimated to be worth $20.5 trillion.

[2] The relationship between infrastructure provision and economic growth is well established in the macroeconomic literature (Röller and Waverman, 2011).

However, the market for direct infrastructure assets is still young and opaque, and specific barriers have to be considered. Political structures and regulations with respect to privatizing are significantly different, immature or absent across the globe. Large investment lot sizes[3], along with an immature secondary market make direct infrastructure an illiquid asset. Furthermore, the specific design and unique characteristics requires specialized knowledge and dedicated resources, so as to provide adequate due diligence and a sufficient risk monitoring process. To generate scale effects in managing infrastructure assets, a sufficient allocation should be made. Although a range of different listed performance benchmarks does exist, the market remains subject to a shortage of data on direct infrastructure performance, and lacks sufficient academic research to understand the general behavior of the asset (Croce, 2011; Inderst, 2010).

The research which deals with direct infrastructure asset allocation basically covers two markets, Australia, the pioneer of privatization and private infrastructure investment, and the United States. Finkenzeller, Dechant and Schäfers (2010) use a sample of major unlisted Australian infrastructure funds to depict direct infrastructure performance over the Q4 1990 to Q1 2009 horizon. The authors construct efficient portfolios for downside risk-averse investors and provide evidence of the diversification benefits of direct infrastructure. The constructed portfolios contain a significant proportion of direct infrastructure, when the expected return is not particularly high. Newell, Peng and DeFrancesco (2011) employ a similar data set over the period Q3 1995 to Q2 2009. Their analysis is based on variance, return and correlation characteristics. They show that direct infrastructure has attractive risk adjusted returns and offers significant diversification benefits against equities and bonds. These results also apply when the impact of the financial crisis is accounted for. Based on a set of different US asset returns and a transaction-based direct infrastructure series, Dechant et al. (2010) analyze the role of direct infrastructure in a conditional shortfall risk framework. They find that infrastructure exhibits unique asset characteristics and they underpin the significance of direct infrastructure for portfolio diversification. Efficient portfolios contain a significant proportion of infrastructure which, however, depends on the expected return and state of the equity market. Moreover, the authors highlight the importance of infrastructure for portfolio diversification in bear markets.

This paper contributes to the existing literature by investigating the role of direct infrastructure in multi-asset portfolios over time, considering different investment scenarios. To construct efficient portfolios, we use a horizon-dynamic algorithm which minimizes Conditional Drawdown at Risk (CDaR), for a given level of expected return. Chekhlov, Uryasev and Zabarankin (2000, 2003,

[3] According to Prequin (2011), an average infrastructure deal size is estimated to be at around US$ 400 million.

2005) define a portfolio's drawdown on a sample path as the drop in the uncompounded portfolio value, compared to the maximum value attained in the previous moments on that sample path. This approach is appropriate for investors who define their allowed losses as a percentage of initial wealth. The CDaR approach is based on stochastic programming and has proven its efficiency in various portfolio management applications, including Rockafellar and Uryasev (2002), Krokhmal, Uryasev and Zrazhevsky (2002), Cheklov et al. (2005) as well as Berkelaar and Kouwenberg (2010). In particular, we firstly construct unconstrained and constrained investment portfolios. Secondly, we introduce the assumption that an investor is averse to falling short of the return on pension liabilities or some predefined target return. Thirdly, we investigate the role of infrastructure when the investor's main aim is to hedge against downside systematic equity market risk.

The article is organized as follows. The next section introduces the data and presents some descriptive statistics. We continue with a description of the methodology. The results of different models are given in section 4.4 and the final section concludes.

4.2 Data and Descriptive Statistics

We employ US total return data from ten different asset classes, which are deflated by the consumer price index. Observations have a monthly frequency and cover the period from Q2 1990 to Q2 2010. The asset selection focuses on a menu of investment opportunities which are typically preferred by institutional investors. In particular, we consider direct infrastructure, large cap stocks, small cap stocks, cash, short, medium, and long-term government and corporate bonds.

The direct infrastructure performance index is based on transactions and is provided by the Center of Private Equity Research (CEPRES). It is a sub-index of a more general CEPRES dataset of private equity investments, which is employed in studies such as Krohmer, Lauterbach and Calanog (2009), Franzoni, Nowak and Phalippou (2011) and Füss and Schweizer (2011). The specific infrastructure data is applied in studies such as Kaserer, Buchner and Schmidt (2009), Dechant et al. (2010), Bitsch, Buchner and Kaserer (2011), as well as Finkenzeller and Fleischmann (2011). The infrastructure index covers a sample of 930 individual operating infrastructure projects in the US and is based on a broad reporting sample of 135 global infrastructure equity investors. The index construction methodology corresponds with Peng (2001) and is based on the Method of Moment Repeat Sales Regression (MM-RSR). A more formal and detailed illustration of the applied procedure and the data implementation process is provided by Schmidt and Ott (2006).

To reflect unbiased direct infrastructure performance, the index is free of survivorship bias, and corrected for gearing, carried interest, management fees and transaction costs, which reflect the illiquidity of the underlying asset. The capitalization of the index adds up to around $27.2 billion of invested equity and only includes sectors which are in accordance with the definition of infrastructure from Kaserer et al. (2009). Figure 1 shows the average sector weights, which are calculated according to capital invested over the entire sample period. The average index shares are 34% for social infrastructure (health care, waste/recycling) and 66% for economic infrastructure (transportation, telecom, (alternative) energy, construction). The relatively high weights for health care, energy and telecom assets are in line with the investment objectives of various types of investors (Probitas, 2011) and reflect direct investment opportunities in the market. Together with a sufficient number of transactions and a high market capitalization, the index constitutes an appropriate tool for benchmarking direct infrastructure performance in the US.

- Insert Figure 1 about here -

The remaining assets are collected from Thomson Reuters DataStream. The general stock market is represented by the S&P 500 Composite series, whereas the S&P 600 small cap series represents the performance of small cap stocks. The Cash index is the JP Morgan JP US Cash 1 month series. To mirror corporate as well as government bond performance, we use the Citigroup US Broad Investment-Grade (USBIG) index series. We choose a duration of 1-5 years for short-term bond performance (US Citigroup USBIG Government 1-5Y and US Citigroup USBIG Corporate AAA/AA 1-5Y), a duration of 3-7 years for medium-term bond performance (US Citigroup USBIG Government 3-7Y and US Citigroup USBIG Corporate AAA/AA 3-7Y) and a duration of 10 or more years (US Citigroup USBIG Government 10+Y and US Citigroup USBIG Corporate AAA/AA 10+Y) to represent long-term bond performance.

- Insert Table 1 about here -

Table 1 presents the descriptive statistics for various asset classes. The infrastructure index does not yield high returns, but is, on the other hand, also not exposed to high levels of standard deviation. Contrary to intuition, small and large cap stocks are not the assets with the highest level of expected return. The returns from both assets are influenced by almost a decade of extreme impacts on the stock market, thus resulting in the presented numbers. Long-term government bonds yield the highest average return over the sample period. This is likely to have been driven by a favorable interest policy in recent years and a capital flow away from the equity into the government bond market.

- Insert Table 2 about here -

Correlations between the returns on various assets are presented in Table 2. It shows that direct infrastructure is not significantly related to any other asset return, but only to cash. Moreover, infrastructure does not exhibit any significant diversification benefits, which means that it is not negatively and significantly correlated to any asset. The significant correlation between infrastructure and cash is essentially intuitive, as both assets provide stable returns. The fact that infrastructure returns are not correlated with other asset returns conforms to the characteristics of infrastructure. Conservative projects, reflected by the return series at hand, provide fundamental and basic services to the economy, and are largely independent of macroeconomic cycles – in contrast to equities or corporate bonds, for example. This asset profile supports the argumentation of previous studies, such as Newell and Peng (2008) and Dechant et al. (2010), who provide evidence that infrastructure constitutes a separate asset class with a unique risk/return profile.

4.3 Methodology

We consider conditional drawdown at risk (CDaR) as a risk measure for portfolio optimization. CDaR is closely related to the concept of conditional value at risk (CVaR) which is defined by Rockafellar and Uryasev (2000, 2002) for general loss distributions. CDaR is dependent on the sample path of the uncompounded value of a portfolio. Chekhlov et al. (2003, 2005) define a portfolio's drawdown on a sample path, as the decline in the uncompounded portfolio value, compared to the maximum value attained in the previous moments on that sample path. The drawdown calculates losses for the most "unfavorable" moment in the past, compared to the current moment. It quantifies, in an aggregated manner, the frequency, as well as the magnitude of portfolio drawdowns over a given time period. This approach is appropriate for investors who define their allowed losses as a percentage of initial wealth. The theoretical concept of drawdown risk is given as follows.

Suppose that the initial portfolio value is equal to 1. The uncompounded portfolio value at time j then equals

$$v_j(x) = \sum_{i=1}^{n} (1 + \sum_{s=1}^{j} r_{is}) x_i \tag{1}$$

where r_{ij} is the return on asset i in time period j, with $j = 1, \ldots, J$. Asset weights in the portfolio are denoted by x_i, $i = 1, \ldots, n$.

The drawdown function $\psi(x, j)$ for a portfolio at time j is defined as the decline in portfolio value, compared to the highest portfolio value achieved before that time moment j.

$$\psi(x, j) = \max_{0 \le k \le j} \left\{ \sum_{i=1}^{n} \left(\sum_{s=1}^{k} r_{is} \right) x_i \right\} - \sum_{i=1}^{n} \left(\sum_{s=1}^{j} r_{is} \right) x_i \tag{2}$$

This means that, for a specified sample path, the drawdown function is defined at each point in time. In order to aggregate all drawdown information over a certain time period, and to evaluate portfolio performance across the entire sample path, one can, for example, choose the Maximum Drawdown (MaxDD)

$$MaxDD = \max_{0 \le j \le J} \left\{ \max_{0 \le k \le j} \left\{ \sum_{i=1}^{n} \left(\sum_{s=1}^{k} r_{is} \right) x_i \right\} - \sum_{i=1}^{n} \left(\sum_{s=1}^{j} r_{is} \right) x_i \right\} \tag{3}$$

or the Average Drawdown (AvDD)

$$AvDD = \frac{1}{J} \int_{0}^{J} \psi(x, j)\, dj \tag{4}$$

as a measure of portfolio risk.

A disadvantage of the Maximum Drawdown is that it focuses only on one single event, the worst case in the sample path. This outcome might be very specific, and risk management based only on this event may be too restrictive. A further extreme is the average drawdown, which accounts for all drawdowns in the sample path. The shortcoming of this measure is that it treats even relatively small deviations as risky outcomes and is prone to averaging out large drawdowns. The Conditional Drawdown at Risk, as demonstrated by Chekhlov et al. (2003, 2005), combines both the drawdown approach and the concept of conditional value at risk. For a given value of the tolerance parameter α, the α-CDaR is defined as the mean of the highest (1-α)*100% of all drawdowns over an analyzed period of time.

If the product $(1-\alpha)J$ is an integer, the CDaR function $\Delta_\alpha(x)$ is defined as

$$\Delta_\alpha(x) = \eta_\alpha + \frac{1}{(1-\alpha)J}\sum_{j=1}^{J}\max\left\{0, \max_{0\le k\le j}\left[\sum_{i=1}^{n}\left(\sum_{s=1}^{k} r_{is}\right)x_i\right] - \sum_{i=1}^{n}\left(\sum_{s=1}^{j} r_{is}\right)x_i - \eta_\alpha\right\} \tag{5}$$

$\eta_\alpha = \eta_\alpha(x)$ represents the threshold which is exceeded by $(1-\alpha)J$ drawdowns. Therefore, $\Delta_\alpha(x)$ is the average of the $(1-\alpha)J$ highest drawdowns in the analyzed sample path.

If $(1-\alpha)J$ is not an integer, the CDaR $\Delta_\alpha(x)$ is the solution of

$$\Delta_\alpha(x) = \min_{\eta}\left\{\eta + \frac{1}{(1-\alpha)J} * \sum_{j=1}^{J}\max\left\{0, \max_{0\le k\le j}\left[\sum_{i=1}^{n}\left(\sum_{s=1}^{k} r_{is}\right)x_i\right] - \sum_{i=1}^{n}\left(\sum_{s=1}^{j} r_{is}\right)x_i - \eta\right\}\right\} \tag{6}$$

Table 3 shows conditional drawdowns of different assets calculated over the full sample period and for various levels of α.

- Insert Table 3 about here -

It can easily be seen that, independent of the confidence parameter, infrastructure is likely to be an attractive asset when an investor's main aim is to protect her portfolio from drawdown risk; only cash is exposed to less drawdown risk, but contemporaneously offers a significantly lower average return. This conforms to the perception of infrastructure as a low-risk, low-return asset and speaks in favor of including infrastructure in portfolios designed to have these properties. It is necessary to bear in mind that these values are calculated over the entire sample period. This does not, of course, exclude the possibility that some changes in these numbers within the considered sample path, may affect time-varying allocations.

Chekhlov et al. (2000) show that CDaR has appealing properties, such as convexity, with respect to portfolio positions, so that linear optimization algorithms can be applied to treat CDaR efficiently. Based on the sample path of the available assets, the optimization problem is formulated as minimizing portfolio drawdown risk, subject to constraints on the expected rate of return. Formally, this is given by

$$\min_{x} \Delta_{\alpha}(x_1,\dots,x_n)$$

Subject to

$$\sum_{i=1}^{n} \bar{r}_i x_i = \kappa \qquad \text{(I)}$$

$$0 \le x_i \le 1, \; i = 1,\dots,n \qquad \text{(II)}$$

$$\sum_{i=1}^{n} x_i = 1 \qquad \text{(III)}$$

Where $\bar{r}_i$ is the expected return on asset i.

Constraint (I) ensures that some predetermined expected portfolio return κ is met. Condition (II) imposes restrictions on the amount of wealth invested in one single asset (no short sales), and condition (III) guarantees that 100% of the available capital is invested. The reduction of the CDaR optimization problem to a linear programming problem is shown by Chekhlov et al. (2003) and is provided in the appendix.

To account for time variation in asset behavior, we employ a dynamic asset allocation procedure. This means that we operate the optimization at each point in time (each month), starting in April 1996. Therefore, the first optimization covers the time frame from May 1990 to April 1996, a sample of 72 observations which is sufficient to obtain meaningful portfolio compositions. We then expand the time frame over which the optimization is performed by one month successively, until our analysis spans the entire time frame from May 1990 to July 2010, with efficient portfolio compositions from April 1996 to July 2010. This expanding window approach yields a time series of allocations for each asset. The optimization procedure thus accounts for changing asset characteristics over time and delivers more meaningful results than a static optimization procedure, which yields only one "optimal" value for each instrument in the portfolio.

At each point in time, we estimate ten efficient portfolios. These ten portfolios comprise the minimum CDaR portfolio (portfolio 1) and the maximum return portfolio (portfolio 10), as well as eight portfolios in between. We refer to portfolio 1-3 as low-return portfolios, portfolios 4-7 as medium-return portfolios, and portfolios 8-10 as high-return. At each point in time, the return distance between two successive portfolios is equal (e.g. the difference in expected return between portfolios 2 and 1 is equal to the difference in expected return between portfolios 3 and 2, and so on). To check for robustness of our results, we perform the optimization in section 4.4.1 with different specifications of the confidence parameter α. These are 0.99, 0.95, 0.90, 0.80 and 0.00. A confidence parameter of zero constitutes a limiting case of the CDaR risk function, which is the average drawdown. When α approaches one, the drawdown function accounts for one single event – the maximum portfolio loss on a sample path. For reasons of clarity, we mostly refer to the results for $\alpha = 0.95$ which constitutes a form of base case.

Although it is intrinsic to the CDaR concept to structure the optimization problem so that the return is maximized for a certain level of portfolio drawdown (because it is convenient for an investor to define the amount of wealth she is willing to risk), we fix an expected return and minimize the respective risk measure. This methodology has the advantage that, at each point in time, we cover the range of possible portfolio compositions from the MinCDaR portfolio to the maximum return portfolio. However, this means that the expected portfolio returns do not exactly match for the different models and for different points in time, which might impede comparability. Nevertheless, this methodology ensures that, for example, a MinCDaR portfolio is always compared to another MinCDaR portfolio. It would make no sense to compare portfolios which have identical levels of absolute return, because expected returns change over time. Furthermore, comparing portfolios with identical returns also creates the problem that one might choose a portfolio with an expected return below that of the MinCDaR portfolio. No rational investor would choose such a portfolio structure. Therefore, our approach guarantees that we always compare a low (medium, high) return portfolio to another low (medium, high) return portfolio and that we choose from a set of efficient portfolios.

4.4 Results

4.4.1 The Role of Infrastructure in Drawdown Efficient Portfolios

The allocations from different CDaR optimizations exhibit two general results. Firstly, as Table 4 indicates, infrastructure is on average mainly allocated to low and medium-expected return portfolios, and, secondly, as shown in Figure 2[4], infrastructure allocations vary significantly over time.

- Insert Figure 2 about here -

- Insert Table 4 about here -

The upper left graph in Figure 2 depicts the allocation to infrastructure in portfolio 1, the graph to the right is the allocation to portfolio 2, and so on. The last graph shows infrastructure weights in portfolio 9. The allocation to portfolio 10 is not reported, as infrastructure plays almost no role.

The fact that infrastructure is, *on average,* primarily placed in low and medium-expected return portfolios derives from the simple fact that infrastructure investments exhibit moderate returns and low drawdown risk. This result applies independently of the chosen confidence parameter, as the absolute levels of average allocations do not vary much for a different α. Only for a confidence level of $\alpha = 0.99$, one can observe a decrease in infrastructure weights in portfolios 3 to 8 compared to portfolios based on lower confidence levels. In this respect, the algorithm replaces infrastructure mainly by short and mid-term bonds, since these assets exhibit lower conditional drawdown risk in previous time periods.

When we analyze *time-varying* infrastructure allocations, we focus on portfolios 1 to 5. This is because we find a relatively clear distribution of infrastructure across time in these portfolios *and* the asset seems to play a major role. Let us, for example, have a closer look at drawdown-efficient portfolios when α is set to 0.95. Theoretical infrastructure weights rise to a maximum of 43% and the asset is – except for MinCDaR portfolios – consistently allocated over time. This implies that infrastructure plays an important role when the aim of an investor is to preserve his real capital, i.e. when reducing drawdown risk is at the center of his investment objectives. Not considering

[4] The graphs for other confidence levels than 0.95 are given by Figures 3-6.

infrastructure therefore implies portfolio compositions which either have a higher drawdown risk for an identical return, or a lower expected return for the same level of drawdown risk[5].

However, we observe some inconsistency in allocations, which means that efficient infrastructure weights vary over time. From Figure 2, it is evident that infrastructure comprises more than 40% (33%, 17%) of total wealth in portfolio 4 (3, 2) in March 2000. This allocation decreases rapidly to below 25% (17%, 8%) in August 2002, and recovers to almost 45% (37%, 26%) again throughout 2007. Since then, it remains relatively stable. A similar allocation pattern holds for portfolio 5, although infrastructure weights recover faster during the impact of the dot.com crisis, and they are, on average, higher. The question rises, as to why the allocation to infrastructure decreases with the dot.com bubble in March 2000 and is followed by a sharp increase some years later. The fact that the allocation to infrastructure decreases along with the decline in the equity market seems to be rather counterintuitive, as one assumes that losses in the equity market (the average monthly loss of the S&P 500 is 1.64% between March 2000 and August 2002) induce an increase in the attractiveness of relatively conservative assets like infrastructure. However, instead of infrastructure, the algorithm allocates short-term corporate bonds and cash. The reason is simple; the average drawdown risk of infrastructure increases as a result of relatively low returns, while the opposite applies to short-term corporate bonds and cash. This example shows that a bear market for equities does not necessarily advocate the inclusion of infrastructure, but short-term assets, such as AAA-rated corporate bonds and money market instruments, are rather preferred. A period of rising infrastructure weights again begins in Q4 2003. This is especially evident in the MinCDaR portfolio, where infrastructure is included, although this portfolio had previously been dominated by cash. The inclusion of infrastructure, at the cost of cash, is a general result in low-return portfolios and explains rising infrastructure weights. From Q3 2003 onwards, the average drawdown risk of cash increases[6], while that of infrastructure decreases contemporaneously. The levels of drawdown risk persist to the end of the period under examination and explain the stable proportion of infrastructure up to July 2010. Although, there are some differences in absolute infrastructure weights when the confidence parameter is changed to 0.00, 0.80 or 0.90, the results remain qualitatively unchanged and the conclusion that infrastructure constitutes a viable asset for low to medium-return portfolios – in which it is consistently allocated – persists. Only for an extreme value of $\alpha = 0.99$, can one observe a substitution of infrastructure by short-term government bonds and cash over the course of the Lehman collapse.

[5] The effect of the inclusion of infrastructure, i.e. the reduction in portfolio drawdown risk for various confidence levels is shown in Table 10.
[6] The increase in unexpected inflation might be the reason for the increase in the drawdown risk of cash. We employ the approach of Fama and Schwert (1977), to proxy for unexpected inflation, and find that unexpected inflation is negatively related to the returns on cash, and that unexpected inflation increases from 2002 to 2004. This induces a contemporaneous decrease in the return on cash and an increase in drawdown risk.

Allocations in portfolios 6 and 7 are highly volatile and strongly reliant on whether mid/long-term bonds or equities are allocated. Depending on the return information available at a given point in time, either infrastructure or mid/long-term bonds or equities are placed in the portfolio. For example, after September 2008, infrastructure weights decrease remarkably, but mid-term government bonds enter the portfolio. Especially the volatility of equity returns entails volatile portfolio compositions with no such consistent allocation patterns, as in lower-return portfolios. It is therefore difficult to make a general statement on the role of infrastructure. Although its average allocation is not particularly low, the asset is, as a logical consequence of moderate returns, not as heavily allocated as in lower-return portfolios. Contrary to the findings for lower-return portfolios, the allocation to infrastructure is sensitive to the confidence level, when the expected return increases. When α is set to lower values, such as 0.00, 0.80 or 0.90, infrastructure is allocated consistently to portfolios 6 to 9 before 2001, while it (almost) disappears, when α is set to 0.95 and 0.99. As already stated, there is a tendency to average out extreme drawdowns for lower levels of α, while a higher confidence parameter, in contrast, tends to account only for very extreme outcomes. This leads to the exclusion of infrastructure before 2001, and to the inclusion of mid-term government bonds, as their 0.99-CDaRs are smaller than those of infrastructure. However, this tendency reverses when α is set to 0.00. These inconsistent results make it impractical to make a general recommendation on the role of infrastructure in portfolios which aim at yield high expected returns, but efficient weights largely depend on the perception of risk.

It should be noted that the presented allocations are extreme outcomes and constitute corner solutions. In reality, fund managers are restricted, either institutionally or through regulatory issues, in allocating wealth to various assets. To reflect this situation, we impose restrictions on portfolio weights. We assume that a representative fund manager has to allocate at least 20%, but not more than 40%, to long-term government bonds and large cap stocks, respectively. Furthermore, in the interest of diversification, no asset, apart from long-term government bonds and large cap stocks, is allowed to exceed a proportion of more than 20% of total wealth. At least 5% of all funds must be allocated to cash, with a maximum allocation of 15%. The average portfolio weights for various levels of α are given in Table 5 and show that infrastructure is a viable asset for portfolio performance, especially in low and medium- return portfolios, but decreases with rising expected returns.

- Insert Table 5 about here -

As a result of the constraints imposed on portfolio weights, the allocation to infrastructure is not as heavy as in unrestricted portfolios, but large cap stocks, long-term government bonds and some cash is placed instead. Only the MinCDaR portfolio contains a higher average proportion of infrastructure, which is a consequence of the restriction on cash. Again, it is important to note that portfolios which are constructed under different constraints are not comparable one to one. While, for example the constrained MinCDaR portfolio exhibits a monthly average return of 0.46%, a comparable return level (0.48%) is obtained from portfolio 5, when asset weights are not constrained. Nevertheless, constrained portfolio compositions, which may reflect institutional investment policy more accurately, deliver results indicating that the inclusion of infrastructure offers clear advantages for portfolio managers, especially in lower return portfolios. This confirms previous findings.

4.4.2 Infrastructure, Pension Liabilities and Target Rate Relative Drawdown Risk

The objective of many investors is not simply to minimize portfolio risk for some given level of expected return, but to accumulate assets which are able to meet their future liabilities (for example, insurance companies or pension funds) or some pre-specified target return which is required by their equity or debt investors. Such a strategy places liabilities or some benchmark return at the center of the investment policy, making it the reference point for evaluating portfolio risk and performance. The concept of drawdown risk is likely to meet these objectives, as it is able to address investor concerns of falling short of these rates.

Pension liabilities can be replicated by certain liability indices, such as the Markit iBoxx US Pension Liability Index series, which is available from Q1 1998 onwards, as well as the Citigroup Pension Liability Index, which starts in Q1 1995. However, none of these indices covers the entire sample period of this study. To overcome this problem, we apply the methodology of Hovenaars, Molenaar, Schotmann and Steenkamp (2008) in constructing a pension liability index. Their approach is based on a log-linear transformation process, and the construction of liability returns $r_{L,t+1}$ is given as follows

$$r_{L,t+1} = \frac{1}{12} rr_{t+1} - D_L (rr_{t+1} - rr_t) \qquad (7)$$

where rr_t is the 10 Year Treasury Yield adjusted to constant maturity and D_L the duration of pension fund liabilities. As in Hoevenaars et al. (2008)[7], an average duration of 17 years is assumed[8]. This self-constructed series is significantly related to the Markit, as well as the Citigroup series, with statistically significant (1%) correlations of 0.65 and 0.44, respectively. This makes it an appropriate tool for depicting liability performance, which is used in the further course of our analysis. To construct liability efficient portfolios, we employ the same methodology as before and now minimize liability relative drawdown risk ($\alpha = 0.95$)[9], while achieving some excess return over liabilities.

The constructed portfolios are dominated by long-term government bonds in low and medium-return portfolios. When higher returns have to be achieved, large cap stocks are allocated at earlier time moments and are, from 2001 onwards, mainly replaced by better performing small cap stocks. In terms of infrastructure weights, we obtain a rather unexpected result. In contrast to the findings in section 4.4.1, infrastructure is not included in any efficient portfolio, regardless of the expected portfolio return, the confidence level and the time moment. Where does this result come from? The valuation of pension liabilities is at the very core of this outcome. Pension liabilities are valued simply by discounting the cash flow of future pension payments via government bond spot curves or swap quotations. As liabilities are usually retained for a long time before they are distributed to the beneficiaries, this places them at the long end of the yield curve and renders their values sensitive to changes in interest rates and other changes in the yield curve. This inherently links the return on pension liabilities to the returns on long term (government) bonds. A significant fall in interest rates, such as during the recession in 2008, therefore has a dramatic impact on the value of pension liabilities, with an increases of almost 20% in value. No other asset apart from long term (government) bonds can match such an increase in value and makes other assets less attractive from a liability point of view.

- Insert Table 6 about here -

[7] The data/methodology used is subject to the condition of constant age groups and pension rights accrued per group over time. The assumption that the pension fund is in a stationary state allows us to describe liabilities as a constant maturity index-linked bond. We further assume that the inflow from pension contributions is equal to the NPV of new liabilities and the current payments of the fund, and additionally ignore taxation issues, demographics and longevity risk. In consequence, interest rate and inflation risk are the only factors which are relevant to the pension scheme.

[8] To check for robustness, we apply different durations to construct liabilities, namely 15, 16, 18 and 19 years. The results, however, do not change fundamentally and are available from the authors upon request.

[9] We checked for robustness by employing confidence levels of 0.99, 0.90, 0.80 and 0.00.

The correlations and betas of liabilities[10] with other assets, as shown in Figure 6, underpin this finding and provide – together with the high expected return on long term government bonds – a rationale for significant long term government bond allocations in liability-efficient portfolios. If the return on an asset is sufficiently high, and moves together with the return on liabilities, it is a viable asset for minimizing liability-relative drawdown risk. Equities are, on average, included, as they offer high expected returns, especially in former years. The reason, why drawdown-efficient portfolios do not contain any infrastructure is straightforward. Firstly, infrastructure returns are lower than those of small caps, large caps and long term government bonds and, secondly, infrastructure does not move together with liabilities, which is also not favorable from a drawdown perspective. This contradicts the reputation of infrastructure as an appropriate asset for pension plan liability matching.

In addition to the liability-driven approach, we benchmark each asset against a fixed target return. Since investors are not homogenous, but have different investment objectives, we consider three different real target returns. These are 2.0%, 3.0% and 4.0% annually. One has to bear in mind that the applied target rates should not be confused with expected returns. While the expected return reflects the return an investor aims to achieve, the target rate is essential for the definition of risk and reflects some level of return, to which the investor is averse to falling short. Therefore, it is not a contradiction to assume an expected return which exceeds the target rate.

- Insert Table 7 about here -

The average portfolio compositions for different targets are presented in Table 7. In accordance with the results from section 4.4.1, we find that infrastructure is, on average, present in low and medium-return portfolios across all target returns. The allocation to infrastructure is higher than in the base model in section 4.4.1 and increases with rising target rates in low-return portfolios, a result which contradicts intuition. However, this outcome can easily be explained by the fact that infrastructure replaces cash. This effect becomes more pronounced the higher the target return is set. The fact that the allocation towards cash diminishes with rising target rates is intuitive. An increase in the target return raises the drawdown risk of cash as a result of relatively low returns, and provides momentum for including an asset which exhibits higher returns, but moderate

[10] The monthly real average return on the liabilities is 0.61%, and the standard deviation is 3.79%. We compare the return and the standard deviation of our self constructed liability series to the Citigroup and the Markit series over matching intervals and find quite similar numbers. While, for example, our series exhibits a nominal return and a standard deviation of 0.71% and 3.77% over the January 1995 to July 2010 period, the corresponding values for the Citigroup series are 0.87% and 3.95%.

drawdown risk – a role played by infrastructure. When the expected return increases, infrastructure is removed more from the portfolio than in our base case; as a logical consequence of relatively low infrastructure returns, this pattern is more conspicuous, the higher the target rate is set. These findings confirm the results from section 4.4.1 and accentuate the role of infrastructure as a viable asset for low-risk portfolios, when investors exhibit different target rates of return.

- Insert Figures 7-9 about here -

In accordance with our previous findings, infrastructure allocations vary over the time horizon, as shown in Figure 7 to 9. The volatility of infrastructure weights increases with an increase in the expected return and in the target rate. As a result of implementing the target return, infrastructure allocations are not as sensitive to short-term bonds, but rather to mid-term (corporate and government) bonds. This result makes sense, as short-term investments become – due to their low expected returns – more unattractive from a target-rate perspective. This sensitivity can be observed over the course of the dot.com and the recent financial crisis, with infrastructure being replaced by mid-term bonds, especially for medium and some higher -return portfolios. Nevertheless, the picture of infrastructure as an asset which is able to contribute mainly to the performance of low-risk and low-return portfolios is clearly evident, as the asset is stable and persistently allocated to those portfolios. Since it tends to replace cash, infrastructure is now allocated to the MinCDaR portfolio across the entire time horizon. Furthermore, infrastructure weights are more stable in low-return portfolios when a benchmark is implemented.

4.4.3 Downside Beta Hedged Portfolios

Ang, Chen and Xing (2006) show that investors demand a premium on equities which move together with the market when it drops. To incorporate this aversion to (equity) market downside risk, we construct portfolios which do not follow the equity market when it is in a poor state – expressed simply, a restriction on portfolio downside beta. We define portfolio downside beta as the weighted sum of individual assets' downside betas. Accordingly, this is given by

$$\beta_p^- = \sum_{i=1}^{n} \beta_i^- x_i \tag{9}$$

Following Ang et al. (2006), we define individual asset downside beta as

$$\beta_i^- = \frac{\text{cov}(r_i, r_m | r_m < 0)}{\text{var}(r_m | r_m < 0)} \tag{10}$$

where r_m is return on the S&P 500. This means that we calculate beta only over those periods when the broad real equity market return is below zero. Average downside betas for different assets are shown in Table 8.

- Insert Table 8 about here -

While infrastructure returns are negatively related to equity market down movements, long-term bonds and especially equities, are exposed to higher systematic downside risk. To construct downside beta hedged portfolios, we impose a further constraint in the optimization problem, which ensures that portfolio downside beta does not exceed a specific, pre-determined value, which is set to 0.4 and 0.2, respectively. Table 9 shows average infrastructure weights for downside beta hedged portfolios.

- Insert Table 9 about here -

It is not surprising that the average share of equities decreases in downside beta (0.4) hedged portfolios, as the downside beta is calculated conditionally on an equity market return series. To achieve higher expected returns, long-term government bonds are partially allocated instead. Infrastructure weights are higher in those portfolios which are intended to yield high returns, compared to non-hedged portfolios. These high allocations in higher return portfolios are associated with the ability of infrastructure to diversify systematic equity risk. When, for example, the proportion of small caps rises in mid 2005, the allocation to infrastructure rises simultaneously. Therefore, if investors wish to earn relatively high returns, but have an aversion towards systematic equity downside risk, they would be well advised to allocate some of their capital to infrastructure, along with equities. However, when long-term government bond returns increase over the course of the financial crisis and begin to enter high-return portfolios in place of equities, the importance of infrastructure for diversifying systematic equity risk decreases, as bonds themselves do not exhibit as high a downside beta as equities. Therefore, the weight of infrastructure, especially in high-return portfolios, depends on the relative weights of bonds and equities. If an investor intends to invest in equities, she is advised to devote some capital to infrastructure for diversification reasons, although this does not apply when the main investment asset is fixed income. In contrast to high-return portfolios, the average proportion of infrastructure decreases in low-return and some medium-return portfolios, but cash and some short-term corporate bonds are used instead.

- Insert Figure 10 &11 about here -

In terms of time-varying asset weights, as shown in Figures 10 and 11, one can further see similar, but smoother sequences of allocations, compared to when portfolios are not downside beta hedged. This results from low downside beta for infrastructure with respect to the equity market and implies that infrastructure is an attractive asset for hedging declines in the equity market. When the restriction on beta is altered to 0.2, the presented results do not change fundamentally, but are more accentuated, which means that the allocation to infrastructure is even lower in low return portfolios, but increases with higher expected returns.

4.5 Conclusion

Direct infrastructure has emerged as a separate asset during recent years and it is now finding its way into institutional investment portfolios. However, the role of direct infrastructure in mixed asset portfolios is, due to data limitations, a barely investigated topic and the question arises as to how much infrastructure is “optimal”. This study aims to fill this research gap, by assessing a row of asset allocation models which reflect the attitudes of different investors. To mirror direct infrastructure performance, we employ a transaction-based index which is provided by CEPRES. The proposed risk measure is the Conditional Drawdown at Risk (CDaR) which was introduced by Chekhlov et al. (2000, 2003, 2005). This measure of portfolio risk is defined as a decline in uncompounded portfolio value, compared to the maximum value attained in the previous moments on a sample path. To account for time-varying asset characteristics, we employ a dynamic asset allocation procedure, which estimates efficient asset weights at each point in time. We firstly minimize CDaR for some given levels of expected returns in unconstrained portfolios, which contain government and corporate bonds of different maturities, cash, small cap as well as large cap stocks and infrastructure. In a second step, to be more in line with the actual behavior of fund managers, we perform the optimization with restrictions on asset weights. Moreover, we investigate the role of infrastructure when pension liabilities and various predefined target returns are the reference point for evaluating portfolio performance. The final model assumes that portfolio managers are averse towards systematic equity market downside risk and imposes a restriction on downside beta when structuring efficient portfolios.

Our results show that infrastructure is allocated significantly to low and medium-return portfolios and infrastructure allocations vary over time. These results are independent of the particular model. We find that infrastructure does not prove to be a good hedge against pension liabilities, but traditional assets such as small caps, large caps and long term government bonds are preferable. This outcome might be associated with the modeling of pension liability returns, which are strongly related with the returns on long-term bonds. The role of infrastructure in a liability framework, especially in consideration of longer holding periods, may constitute a promising topic for further research.

When asset returns are targeted against some predetermined benchmark to mirror capital cost, the role of infrastructure in low-risk portfolios is even more accentuated. Due to the inability of cash to achieve higher return targets, infrastructure is weighted more heavily.

As infrastructure does not correlate with equity returns in down markets, it proves to be a valuable hedge against downside systematic risk which also results in portfolio compositions that exceed those in current investment portfolios.

The proposed models can not demonstrate exactly how much infrastructure should be allocated to a multi-asset portfolio, as this depends on various parameters, such as the investor's expected return, her perception of risk, some target return or the market phase. Furthermore, our results do, not necessarily suggest that investors should reallocate their portfolios and increase their allocation to infrastructure, as we also do not know exactly how much infrastructure is already allocated. However, there are many indications that the actual proportion of infrastructure is, on average, below that suggested by our models.

In summary, we find stable and conclusive evidence that infrastructure can contribute to portfolio performance, especially in low and medium-return portfolios, and that the inclusion of infrastructure may deliver a better risk-return tradeoff than conventional portfolio allocations, which comprise mainly stocks and bonds. This insight should be especially useful for investors whose aim is not to earn superior returns, but to protect their portfolios from extreme declines in value.

References

References Infrastructure Asset Allocation

Ang, A., Chen, J. & Xing, Y. (2006). Downside Risk. *Review of Financial Studies*, 19(4), 1191-1239.

Araújo, S. & D. Sutherland (2010). Public-Private Partnerships and Investment in Infrastructure. *OECD Economics Department Working Papers*, *803*, OECD.

Bawa, V. S. (1975). Optimal Rules for Ordering Uncertain Prospects. *Journal of Financial Economics*, 2(1), 95-121.

Bawa, V. S. & Lindenberg, E.B. (1977). Capital Market Equilibrium in a mean-lower partial moment framework. *Journal of Financial Economics*, 5(2), 189-200.

Berkelaar A. & Kouwenberg, R. (2010). A Liability-Relative Drawdown Approach to Pension Asset Liability Management. *Journal of Asset Management*, 11(2/3), 194-217.

Bond, S. A., Hwang & S., Mitchell, P. Satchell, S. E. (2007). Will Private Equity and Hedge Funds Replace Real Estate in Mixed-Asset Portfolios? *Journal of Portfolio Management*, 33(5), 74-84.

Bond, S. A. & Patel, K. (2003). The Conditional Distribution of Real Estate Returns: Are Higher Moments Time Varying? *Journal of Real Estate Finance and Economics*, 26(2/3), 319-339.

Bitsch, F., Buchner, A. & Kaserer, K.,(2010). Risk, Return and Cash Flow Characteristics of Infrastructure Fund Investments. *European Investment Bank Papers*, 15(1), 106-136.

Chekhlov, A., Uryasev, S. & Zabarankin, M. (2000). Portfolio Optimization with Drawdown Constraints, *Research Report 2000-5*. University of Florida.

Chekhlov, A., Uryasev, S. & Zabarankin, M. (2003). Portfolio Optimization with Drawdown Constraints, Asset and Liability Management Tools, *Risk Books*, London.

Chekhlov, A., Uryasev, S. & Zabarankin, M. (2005). Drawdown Measure in Portfolio Optimization. *International Journal of Theoretical and Applied Finance*, 8(1), 1-46.

Croce, R. D. (2011). Pension Funds Investment in Infrastructure: Policy Actions, *OECD Working Papers on Finance, Insurance and Private Pensions 13*, OECD Publishing.

Dechant, T., Finkenzeller, K. & Schäfers, W. (2010). Real Estate: A Victim of Infrastructure? Evidence from Conditional Asset Allocation. *IREBS Infrastructure Research Working Paper Series*, 2.

Dudkin, G. & Välilä T. (2005). Transaction Costs in Public-Private Partnerships: A First Look at the Evidence. *Economic and Financial Report 2005/03*, European Investment Bank (EIB).

Estrada, J. (2008). Mean-semivariance optimization: a heuristic approach. *Journal of Applied Finance, Spring/Summer*, 57-72.

Fama, E.F. & Schwert, G.W. (1977). Asset returns and inflation. *Journal of Financial Economics,* 5, 115–146.

Finkenzeller, K. & Fleischmann, B. (2011). Real Estate: The interactions Between Direct and Securitized Real Estate and its Relationship to Real Estate. *IREBS Infrastructure Research Working Paper Series*, 4.

Finkenzeller, K., Dechant, T. & Schaefers, W. (2010). Infrastructure: a new dimension of real estate? An asset allocation analysis. *Journal of Property Investment and Finance,* 28(4), 263-274.

Franzoni, F., Nowak E. & Phalippou, L. (2011). Private equity performance and liquidity risk. *Journal of Finance, (forthcoming).*

Fuess, R. & Schweizer, D. (2011). Dynamic Interactions between Venture Capital Returns and the Macroeconomy: Theoretical and Empirical Evidence from the United States. *Review of Quantitative Finance and Accounting, (forthcoming).*

Harlow, W. V. & Rao, R.K.S. (1989). Asset Pricing in a Generalized Mean-Lower Partial Moment Framework: Theory and Evidence. *Journal of Financial and Quantitative Analysis*, 24(3), 285-311.

Hoevenaars, R.P., Molenaar, R.D., Schotman, P.C. & Steenkamp T.B. (2008). Strategic Asset Allocation with Liabilities: Beyond Stocks and Bonds. *Journal of Economic Dynamics and Control*, 32(9), 2939-2970.

Idzorek, T. & Armstrong, C. (2009). Infrastructure and Strategic Asset Allocation: Is Infrastructure an Asset Class? *Ibbotson Research* (January).

Inderst, G. (2010). Infrastructure as an asset class. *European Investment Bank Papers*, 15(1),

70-106.

Inderst, G. (2009). Pension Fund Investment in Infrastructure. *OECD Working Papers on Insurance and Private Pensions*, 32.

Jain, S. (2008). Investing in Developed Country Private Infrastructure Funds. *Citi Alternative Investments Research Paper Series.*

Kaserer, C., Buchner, A., Schmidt,D. & Krohmer, P. (2009). Infrastructure Private Equity. *Center of Private Equity Research*.

Krohmer, P., Lauterbach & L.,Calanog, V. (2009). The bright and dark side of staging: Investment performance and the varying motivations of private equity. *Journal of Banking and Finance,* 33(9), 1597-1609.

Krokhmal, P., Uryasev, S. & Zrazhevsky, G. (2002). Risk management for hedge fund portfolios: A comparative analysis of linear portfolio rebalancing strategies. *Journal of Alternative Investments,* 5(1), 10–29.

Mahmudova, M., Sharma, G., Rey, Y. (2011). Global Infrastructure Finance Review. *Infrastructure Journal*.

Mansour, A., Nadji, H. (2007). Performance Characteristics of Infrastructure Investments. *RREEF Research* (August).

Mansour, A. & Patel, J. (2008). Infrastructure Goes Global. *RREEF Research* (October).

Markowitz, H. (1952). Portfolio selection. *Journal of Finance*, 7, 77-91.

Markowitz, H. (1959). Portfolio selection: efficient diversification of investments. *New York: John Wiley and Sons.*

Newell, G., Chau K. W. & Wong, S. K. (2008). The Significance and Performance of Infrastructure in China. *Journal of Property Investment & Finance,* 27(2), 180-202.

Newell, G. & Peng, H.W. (2008). The Role of U.S. Infrastructure in Investment Portfolios. *Journal of Real Estate Portfolio Management*, 14(1), 21-33.

Newell, G., Peng, H.W. & De Francesco, A. (2011). The performance of unlisted infrastructure in investment portfolios. *Journal of Property Research,* 28(1), 59-74.

Organisation for Economic Co-operation and Development (2006). Infrastructure to 2030 Telecom, Land Transport, Water and Electricity. *OECD Publishing*.

Organisation for Economic Co-Operation and Development (2007). Infrastructure to 2030 Volume 2 Mapping Policy for Electricity, Water and Transport. *OECD Publishing.*

Peng, L. (2001). Building a Venture Capital Index. *Yale ICF Working Paper 00-5.*

Peng, H.W. & Newell, G. (2007). The Significance of Infrastructure in Australian Investment Portfolios. *Pacific Rim Property Research Journal*, 13(4), 423-450.

Preqin (2011). Infrastructure. *The Preqin Quarterly Q3*.

Probitas Partners (2011). Infrastructure Market Review and Institutional Investor Trends Survey for 2011.

Rockafellar, R.T. & Uryasev S. (2000). Optimization of Conditional Value-at-Risk. *Journal of Risk*, 2(3), 21-41.

Rockafellar, R.T. & Uryasev S. (2002). Conditional Value-at-Risk for General Loss Distributions. *Journal of Banking and Finance,* 26(7), 1443-1471.

Roedel, M. & Rothballer, C. (2011). Infrastructure as Hedge against Inflation – Fact or Fantasy. *Working Paper.* Technical University of Munich (TUM).

Rothballer,C.& Kaserer C. (2011). Is Infrastructure Really Low Risk? An Empirical Analysis of Listed Infrastructure Firms. *Working paper*. Technical University of Munich (TUM).

Röller, L.H. & Waverman, L. (2001). Telecommunications Infrastructure and Economic Development: A Simultaneous Approach. *American Economic Review,* 91(4), 909-923.

Schmitt, D. & Ott, T. (2006). Modelling a Performance Index for Non-traded Private Equity Transactions: Methodology and Practical Application. *Research Paper*, Center of Private Equity Research.

Singhal, S., Newell, G. & Nguyen, T.K. (2011). The Significance and Performance of Infrastructure in India. *Journal of Property Research*, 28(1), 15-34.

Wagenvoort, R., de Nicola, C. & Kappler, A. (2010). Infrastructure Finance in Europe: Composition, evaluation and crisis impact. *European Investment Bank Papers,* 15(1), 16-39.

List of Tables and Figures

Paper 4