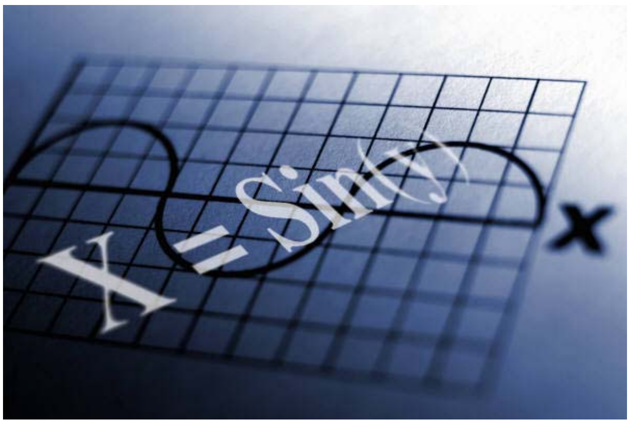
Colonial First State Global Asset Management

Infrastructure Research Paper

16th January 2009

Constructing an investment return series for the UK unlisted infrastructure market: estimation and application

- **The global infrastructure investment community is hamstrung by a lack of adequate data surrounding unlisted infrastructure performance outside Australia. In response, this paper aims to estimate a UK unlisted infrastructure series - something not achieved so far by the infrastructure research sector.**
- **In order to do this, we explore a variety of methodologies. These methods draw on information from different asset classes and geographical markets.**
- **The estimated unlisted series determined to be the most appropriate has lower volatility relative to UK listed infrastructure and lower correlation with both UK listed infrastructure and UK equities. Additionally, it is based on data from the same geographical market and the same underlying asset market.**
- **This constructed series has numerous potential applications, including performance benchmarking, market cycle analysis and portfolio construction.**
- **As a case study, we explore what the optimal capital allocation between unlisted and listed infrastructure investment vehicles in the UK is. Our results indicate that the optimal allocation between unlisted and listed infrastructure is approximately 90% and 10% respectively.**



1. Introduction

Interest in infrastructure as an asset class has increased over recent years due to the shift to yield-based products required by ageing populations worldwide. This demand has been met by the increased willingness of governments to allow private sector participation in infrastructure through privatisation initiatives and public-private partnerships (PPPs). These trends, accompanied by greater investor awareness and understanding, have led to infrastructure's emergence as a genuine asset class, marked by a growing range of investment products.

In mature markets such as Australia, performance measures for both listed and unlisted infrastructure are widely available. However, in other regions such as the UK, no comparable unlisted infrastructure time series exist; presenting a major information gap for analysts and investors alike. This paper aims to address this situation by seeking to construct an unlisted infrastructure return performance series for the UK market.

The paper is structured as follows: Section 2 explores various approaches in estimating a UK unlisted infrastructure series. Section 3 presents the estimation results and identifies the most appropriate series based on a combination of conceptual and mathematical criteria. The estimated series forms the basis for a case study in Section 4, which tries to determine the optimal allocation of capital between UK listed and unlisted infrastructure. Summary remarks are made in Section 5. A Technical Appendix follows this which explores our chosen estimation method in greater detail.

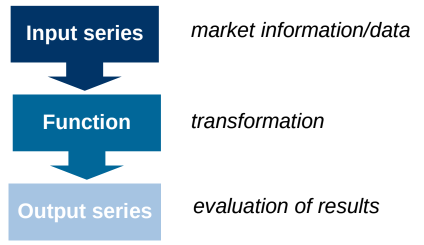
2. Estimating an unlisted infrastructure return series

There exist two main infrastructure investment vehicles; listed infrastructure and unlisted infrastructure. While the underlying assets are essentially the same, the actual return performance can differ significantly. Listed returns tend to be relatively more volatile compared with unlisted returns. This is partly attributable to different methods of valuation. Listed returns are traded on an equity exchange and are therefore subject to stock market gyrations. Unlisted returns are based on an appraisal-based valuation method, which produces a much more stable return profile. Therefore, one would expect that any estimated unlisted series should also exhibit these features.

Two aspects must be considered when trying to construct an unlisted infrastructure return series for the UK (UIUK). The first aspect is selecting the underlying data to be used as an input series. This is analogous to the explanatory or independent variable used in regression analysis parlance. The second aspect is determining the method of transforming the input series. We refer to this as the function. Together, these combine to produce an output series. This process for constructing the series is depicted in Figure 1.

Figure 1

Process for series construction



Source: CFS Research

In choosing potential input series to use for estimating UK unlisted infrastructure, we focus on the 'real asset' universe, given the similar characteristics of these asset classes. In addition, we limit the input series to the UK and Australian markets. Australia was chosen because it has a similar investment environment to the UK, featuring a mature real asset investment sector complete with readily available data.

Data series

All analysis uses monthly data over the ten years to June 2008. Below, we briefly provide details of the data sources used:

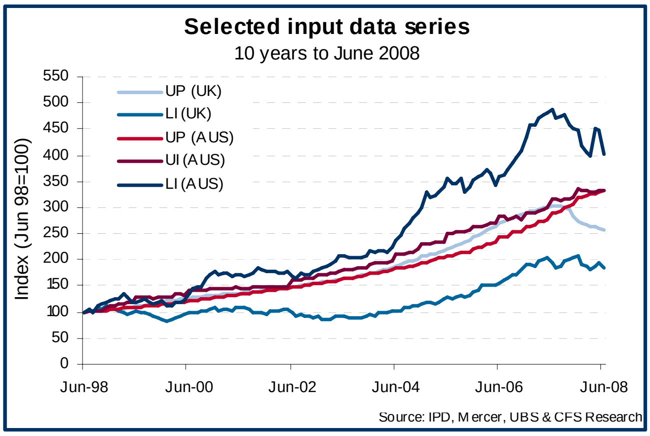
- The Australian listed infrastructure series is the UBS infrastructure and utilities accumulation index. This series has 16 constituents with a combined market capitalisation of around A$48 billion as at June 2008.
- The Australian unlisted infrastructure series is a simple average of five wholesale Australian diversified infrastructure fund returns with varying inception dates. These include the AMP Diversified Infrastructure Equity Fund (Sept 1995), the Colonial First State Wholesale Infrastructure Income Fund (Oct 2003), the Perpetual Diversified Infrastructure Fund (Jan 2005), Hastings' The Infrastructure Fund (Oct 2000), and the Utilities Trust of Australia (Dec 1994). Unfortunately the size of the Australian unlisted infrastructure market is not reported.
- The UK listed infrastructure series is the UBS Infrastructure and utilities accumulation index for the UK. It is comprised of 12 stocks with a combined market capitalisation of approximately A$146 billion as at June 2008.

- The Australian unlisted property series is the Mercer unlisted property fund index (MUPFI) which tracks the performance of 13 large wholesale property funds with a total market capitalisation of around A$32 billion as at June 2008.
- The UK unlisted property series are from the Investment Property Databank (IPD) which measures the performance of property at the asset level, tracking around 3,800 individual properties with a total value of A$89 billion as at June 2008. This is used since there is no UK equivalent to the Australian MUPFI. However, as is the case in Australia, the IPD performance series is assumed to be a good proxy[1].

Figures 2A and 2B plot the series in index form and rolling annual returns respectively. Annual returns are shown order to highlight cyclical patterns in the series.

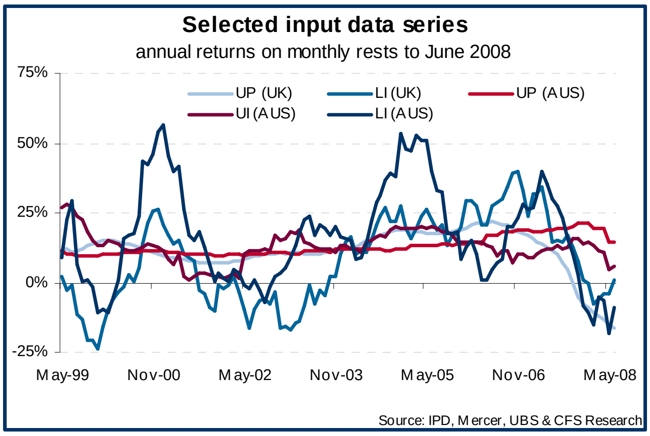
As we can see from the charts, the two listed infrastructure series tend to exhibit higher volatility relative to the two unlisted property and Australian unlisted infrastructure series. It is interesting to see that, in relative terms, Australian listed infrastructure has outperformed the other series over the ten years to June 2008, increasing four times over the period. In contrast, UK listed infrastructure has shown the least impressive performance, managing to only double over the same time frame.

Figure 2A



The strong performance of Australian listed infrastructure relative to the UK is largely explained by a combination of factors such as the higher prevalence of external management (and higher accompanying leverage), and a higher proportion of non-utility infrastructure assets (which typically generate higher returns). Furthermore, the influence from the broader equity market in both countries provides another explanation for this disparity. While UK listed infrastructure has underperformed relative to Australian listed infrastructure, it has outperformed compared to the UK equity market which saw relatively no growth over the ten years to June 2008.

Figure: 2B



We propose two broad techniques for estimating a UK unlisted infrastructure series. The first method involves constructing a variety of ratios based on the input data series. These ratios form the function aspect as described in Figure 1 and are used to adjust our chosen input series.

The second method features a more sophisticated transformation, allowing the characteristics of one series to be imposed onto another. Each of these methods is discussed below.

Method 1: Ratio analysis

The intuition behind ratio analysis is that the relationship between one pair of return series for a given market segment (defined by geography, asset class/sector and/or investment vehicle) is representative for similar asset return series in another market segment.

For instance, consider return time series Y_{At} and X_{At} for country A, and Y_{Bt} and X_{Bt} for country B. Our conceptual model postulates that

$$\frac{Y_{At}}{X_{At}} \approx \frac{Y_{Bt}}{X_{Bt}} \qquad \text{. . . (1)}$$

In a practical setting, equation (1) may apply to property and infrastructure markets, where we may expect the relationship (or ratio) between property and infrastructure returns in the UK to mirror that of Australia.

[1] The IPD and Mercer return series for Australian property exhibit a high degree of correlation: in excess of 0.97.

The model represented by (1) can also be expressed as

$$Y_{At} \approx \left(\frac{Y_{Bt}}{X_{Bt}}\right) X_{At} \qquad ...(2)$$

$$Y_{At} \approx \theta X_{At} \qquad ...(2')$$

Expression (2′) suggests a linear relationship between Y_{At} and X_{At} for a given country where θ represents a parameter value based on information (i.e., the ratio of two return series) contained by country B. In practice, if Y_{At} is an unobservable return time series (in this case, it represents the unlisted return series for the UK infrastructure market), it can be estimated using observed information contained in series X_{At} and the parameter θ.

An important practical aspect of this model is the choice of the input time series (X_{At}) as well as the series chosen (i.e., Y_{Bt} and X_{Bt}) to estimate the function θ. Table 1 outlines four proposed series for estimating Y_{At} based on various combinations of property and infrastructure return series for the Australian and UK investment markets.

Table: 1

Various forms of the ratio model

Series	Y_{At}	θ	X_{At}	Assumption
S1	UI_{UK}	$\frac{UI_{AUS}}{UP_{AUS}}$	UP_{UK}	Relationship between unlisted infrastructure and unlisted property is the same across both the UK and Australia
S2	UI_{UK}	$\frac{UP_{UK}}{UP_{AUS}}$	UI_{AUS}	Relationship between the UK and Australian unlisted infrastructure markets is the same as unlisted property in these markets
S3	UI_{UK}	$\frac{UI_{AUS}}{LI_{AUS}}$	LI_{UK}	Relationship between listed and unlisted infrastructure is the same across both the UK and Australia
S4	UI_{UK}	$\frac{LI_{UK}}{LI_{AUS}}$	UI_{AUS}	Relationship between UK and Australian unlisted infrastructure is the same as listed infrastructure in these markets

Source: CFS Research

The approach implied thus far uses an estimation window for θ spanning the entire sample period, which is 10 years. This assumes a fixed or constant relationship between the ratio variables.

However, this relationship may vary over time in accordance with market cycles and/or structural changes. We can accommodate this idea by allowing the window for estimating θ to be shorter than the sample period. This produces a rolling estimate instead of the fixed value described previously, introducing an element of dynamism. For simplicity, we adopt the 10-year horizon throughout the remainder of the report.

Method 2: Fourier analysis

An alternative and more sophisticated method utilises Fourier analysis to transform a listed UK infrastructure return series into an estimate for an unlisted UK infrastructure return series. This method assumes that listed infrastructure returns are some combination of the performance of the underlying infrastructure assets and the general equity market which is impacted by capital market issues.

If we could approximate and remove the equity market ‘noise’, then the residual would be an estimate of the return performance of an unlisted infrastructure series. While both of these processes are unobservable, we can gain some insight to the characteristics of an unlisted infrastructure series from analysing the Australian unlisted infrastructure return series – which is observable.

Using Fourier analysis we can transform[2] a time series into its individual cyclical components then adjust the magnitude of these cyclical components and reconstruct the time series into a series such that it has the variability of another time series. Fourier analysis has many applications in electrical engineering, vibration analysis, acoustics, optics and signal and image processing.

Figure: 3

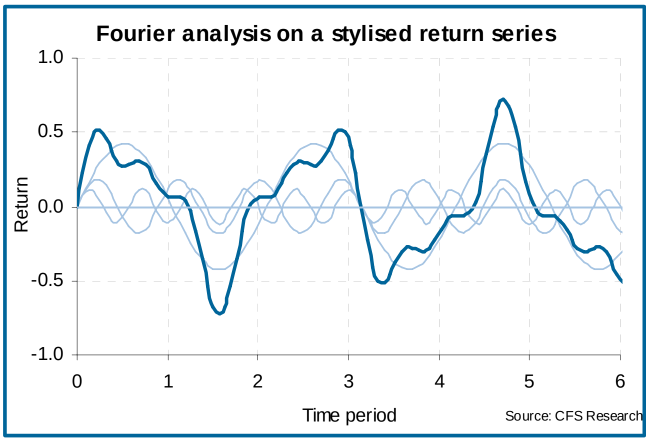


Figure 3 illustrates the concept using a stylised time series. The vertical axis represents investment return while the horizontal axis shows the time period considered. The darker coloured series, which can be

[2] Note we use the Discrete Fourier Transformation (DFT).

thought of as an actual return series, is constructed from summing the four individual lighter coloured cyclical series.

Using this technique we aim to impose the variability found in the Australian unlisted infrastructure return series, using a transformation function $\psi(.)$, onto the UK listed infrastructure return series. Formally, the series we estimate using the Fourier method is denoted as:

$$UI_{UK} \approx \psi(LI_{UK}) \qquad ...(3)$$

The value in the approach is that it will help ensure the generated UK unlisted infrastructure performance series displays a more stable, less volatile profile as we would expect to see in such a time series.

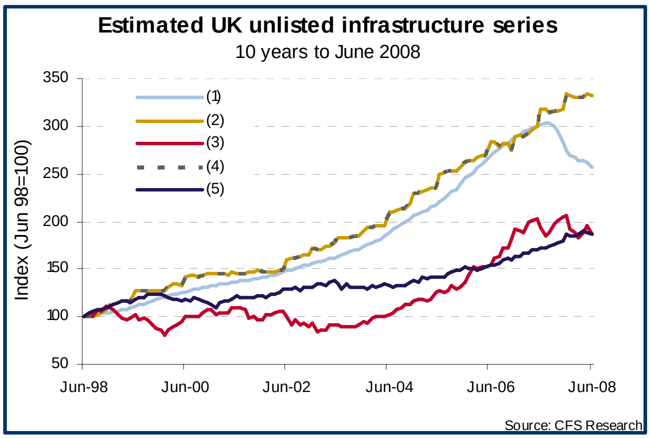
The use of listed infrastructure returns does have some potential issues which need to be considered. The main one is that in recent years listed infrastructure funds have morphed into quasi-financial vehicles which have made greater use of 'financial engineering' to deliver their return to investors. Consequently, the risk-return profile of the sector as a whole has changed – moving away from the stable defensive characteristics of the underlying infrastructure assets. However, this has been more evident in Australia than the UK.

[Please refer to the technical appendix at the end of this report for a more detailed explanation of this estimation technique.]

3. Estimation results and evaluation

This section presents the various constructed UK unlisted infrastructure performance series resulting from the two methods introduced in the previous section. Figure 4A illustrates the five estimated UK unlisted infrastructure indices, whereas annual returns for each series are displayed in Figure 4B.

Figure 4A

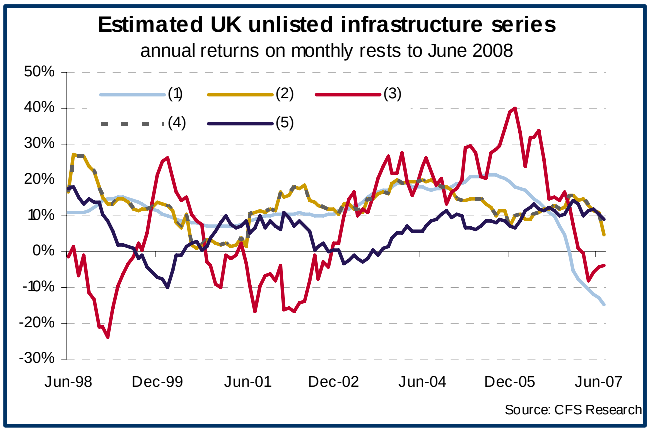


Because the indices are rebased by the chosen ratio term, series (2) and (3) are identical in Figures 4A and 4B.

Together, the charts raise some interesting observations:

- Series (1), which uses UP_{UK} as a proxy for UI_{UK}, exhibits a significant downturn since 2007, reflecting the recent poor performance of direct property in the UK. As expected, it produces a return profile which is similar to that of UP_{UK}, but with a less pronounced fall.
- The strong performance of Series (2) and (4) mirrors the strong performance of the input series UI_{AUS}. If maximising the estimated return was the only objective, these series would be the obvious choices given their superior historical performance.
- The two series based on LI_{UK} (3) and (5) exhibit the lowest returns due to the relatively poor long-term performance of listed UK infrastructure. Series (3), however, exhibits higher volatility than Series (5).

Figure 4B



Criteria for selecting the best series

We now proceed to a more rigorous comparison of the series, based on formal criteria. Our criteria consist of two statistical and two conceptual attributes.

Ideally, the UI_{UK} series should have the following characteristics:

- lower volatility than the LI_{UK} series. This is intuitive as we would expect the appraisal-based valuation method of unlisted infrastructure to result in a more smoothed return series than listed infrastructure.
- less correlated with UK Equities than the LI_{UK} series. A similar logic applies here.

- The input series should be from the same market – in this case, the UK[3]. This accounts for idiosyncratic movements in markets which are likely to be domestic in scope. Examples include changes in economic conditions, bond rates, monetary policy and other shocks.
- The input series should be based on the same underlying asset – in this case, infrastructure. Note that this does not necessitate the use of an unlisted input series. The logic here is that a given underlying asset should deliver the same long-return return profile, irrespective of whether it is listed or unlisted.

We assess the various series on the basis of these criteria as reported in Table 2. Four of the five series fail at least one criterion. For example, Series (1) scores well on the statistical criteria but has the disadvantage of being based on property rather than infrastructure. Series (2) and (4), on the other hand, are not based on input series from the UK market. Series (3), which satisfies both the aforementioned qualitative criteria, fails in a statistical sense. Only Series (5) meets all four criteria: it is constructed using the most appropriate variables; while the transformation method ensures that the series displays the desired statistical characteristics.

Table 2

Evaluation matrix

Criterion	S1	S2	S3	S4	S5
Lower volatility than LI_{UK}	Yes	Yes	No	Yes	Yes
Less correlated with UK equities	Yes	Yes	No	Yes	Yes
Input series from same market	Yes	No	Yes	No	Yes
Input series based on same underlying asset	No	Yes	Yes	Yes	Yes

Source: CFS Research

Unlisted UK infrastructure returns series

Having decided that Series (5) has the most desirable features, we now present the constructed UK unlisted infrastructure return series.

Figure 5A illustrates the annual returns, based on monthly rests, for the estimated unlisted UK infrastructure versus listed UK infrastructure. While Figure 5B presents the Australian analogue.

As can be seen, the estimated unlisted UK series displays significantly less variability than the listed UK infrastructure series. This is comparable to the Australian result.

Figure 5A

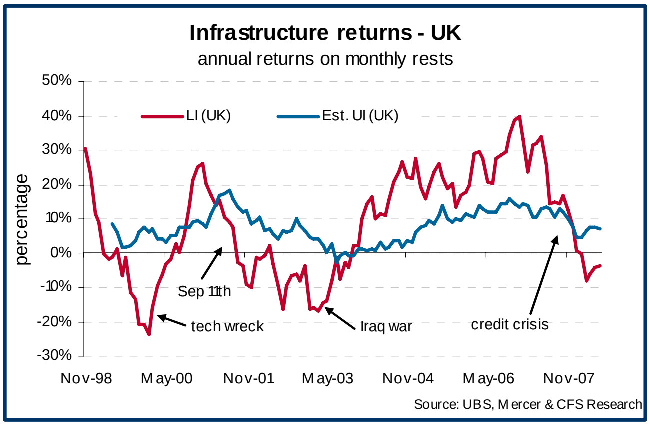


Figure 5B

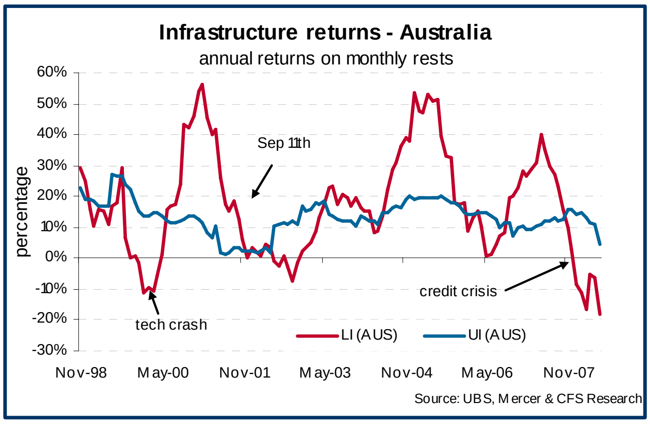


Table 3

Infrastructure return performance metrics

10 years to June 2008 based on monthly rests

	Australia		UK	
	LI	UI	LI	(Est.) UI
Return statistics				
Monthly return	1.2%	1.0%	0.6%	0.7%
Annual return	14.9%	12.8%	6.4%	7.9%
Stardard Deviation	14.4%	6.5%	12.2%	5.4%
Correlation				
With listed infrastructure	1.00	0.23	1.00	0.14
With equities	0.48	0.18	0.38	0.22
Benchmarking				
Inflation*	2.9%	2.9%	2.9%	2.9%
Govt. bond rate	5.7%	5.7%	4.8%	4.8%
Spread to inflation	12.0%	9.9%	3.5%	5.0%
Spread to Govt. bond rate	9.1%	7.0%	1.6%	3.1%

* RPI for the UK and CPI for Australia   Source: ABS, IRESS, Mercers, ONS, UBS & CFS Research

[3] While the *input* series should be from the same market, this does not necessarily preclude the use of a *parameter* estimate based on data from another market.

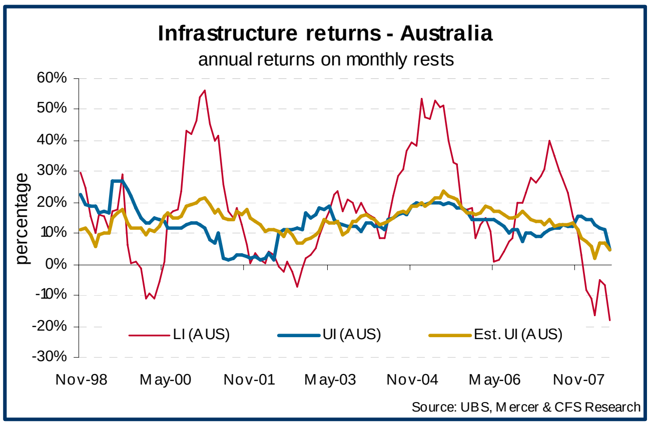
Table 3 presents some summary statistics for the estimated UK unlisted and UK listed infrastructure returns as well as the Australian unlisted and listed infrastructure return series.

The Table highlights that the estimated UK unlisted infrastructure return series does display the desired characteristics. These include; lower volatility than listed UK infrastructure with an annualised standard deviation on monthly returns of 5.4% compared to 12.2% for the latter. The correlation between the estimated UK unlisted and UK listed infrastructure return series is relatively low (0.14) and is comparable to that for the Australian result (0.23). Additionally, the estimated series displays a lower correlation coefficient with UK equities (0.22) compared the UK listed infrastructure (0.38).

Finally, a comparison is made between the estimated UK unlisted infrastructure return series and that of inflation, as measured by the Retail Price Index (RPI) and the 10 year government bond rate. This is done as we would expect the unlisted return series to greater than both of these indicators as is the case in Australia. As the Table shows, there is a positive spread between the unlisted UK infrastructure return series and the two indicators, although not to the same magnitude as in Australia. Therefore the method used generates an unlisted infrastructure return series that meets all three of our criteria.

This is further demonstrated when comparing the actual Australian unlisted infrastructure (UI_{AUS}) return series with an estimate using the Fourier transformation method. Figure 6 shows three time series; one which is the actual return series for Australian unlisted infrastructure and an estimate of the same series constructed via transforming the Australian listed infrastructure return series. For comparison, we include the actual Australian listed infrastructure return series to illustrate how the method works by reducing the variability in the listed returns.

Figure 6



While not a perfect match, the impact of the Fourier transformation is evident as the estimated unlisted Australian return series derived from the listed Australian infrastructure return series displays a profile much similar to that of the actual unlisted series.

Any divergence between the actual and estimated unlisted Australian infrastructure return series tends to coincide with the extreme movements observed in the listed return series, such as around 2000 and 2004 as well as 2006 and 2007.

4. Case study: portfolio construction

The newly constructed UK unlisted infrastructure return series can now be used in a number of interesting situations, such as:

- benchmarking the performance of individual UK unlisted infrastructure funds
- analysing market cyclical patterns over time
- portfolio construction, including determining the optimal allocation of capital between UK listed and unlisted infrastructure.

We perform the third example in what follows. The objective of portfolio construction is to determine a set of weights which describe the proportion of capital an investor should allocate to the assets in their portfolio. The weights are the outcome of a constrained optimisation problem which deliver a portfolio with the lowest possible variance for a given portfolio return.

Table 4

Portfolio construction

Total returns based on 10 years to June 2008

Sector	Return	Std Dev	SR	Optimal portfolio
LI_{UK}	6.4%	12.2%	0.52	10%
Est. UI_{UK}	7.9%	5.4%	1.45	90%
Portfolio	7.7%	5.2%	1.49	100%

Source: CFS Research

Table 4 presents the optimal weightings for a portfolio consisting of UK listed and unlisted infrastructure over the ten years to June 2008. As can be seen, an allocation to listed and unlisted infrastructure of approximately 10% and 90% respectively maximises the risk-adjusted portfolio return, as measured by the Sharpe Ratio[4]. The high weighting for the estimated

[4] The Sharpe Ratio is calculated by taking the quotient of the portfolio's excess return to the portfolio's standard deviation.

unlisted UK infrastructure return series is due to the negative impact of the credit crisis on the performance of listed UK infrastructure over the year to June 2008.

This result is not too dissimilar with the optimal allocation of capital between Australian listed and unlisted infrastructure investment vehicles – with a greater weighting to unlisted infrastructure than to listed infrastructure. [See CFS Research Notes, 'A simple asset allocation model for investing capital', 31 October 2003 and 'Allocating capital between Australian listed and unlisted direct infrastructure investments', 30 March 2008[5]]

5. Summary remarks

This paper aims to fill a gap in the infrastructure research space by estimating an investment return series for the UK unlisted infrastructure market.

In order to estimate a UK unlisted infrastructure series, we explore a variety of estimation methods. These draw on information from different asset classes and geographical markets, and adopt different mathematical approaches.

We find that the Fourier-transformed series, which removes listed equity market noise, displays superior properties. These include lower volatility and weaker correlation with UK equities than the listed UK infrastructure series. The series also has conceptual merit as it uses data based on the same underlying asset and in the same market.

We use this newly estimated series to model the optimal capital allocation between unlisted and listed infrastructure in the UK. Our results indicate that a desired strategic allocation between unlisted and listed infrastructure is approximately 90% and 10% respectively. This finding is in line with the optimal allocation for Australian listed and unlisted infrastructure investment vehicles.

The estimated unlisted series has a range of potential analytical applications in addition to the portfolio optimisation performed in this paper, such as performance benchmarking. The estimation method may also be applied to other countries and markets across the world[6]. These are avenues for further research.

[5] Note, that the report employs desmoothed returns for Australian unlisted infrastructure as is the standard practice observed in the literature. However, the difference between the desmoothed Australian unlisted infrastructure series and the original series is negligible so we focus solely on the original series.

[6] Readers interested in obtaining similar series for other countries may contact CFS Research.

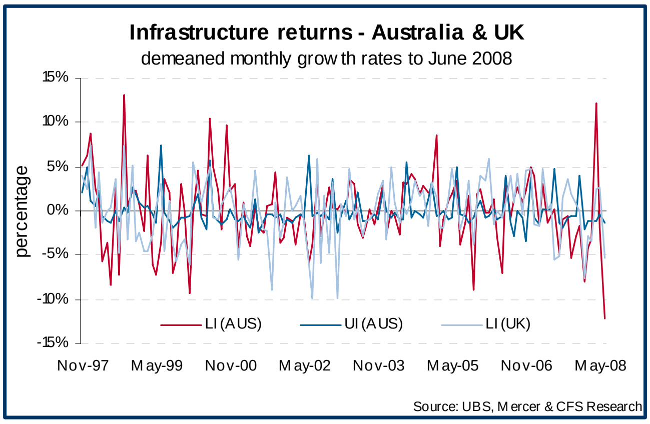
6. Technical appendix – Fourier analysis

This section presents a more detailed look at the methodology used to estimate an unlisted UK infrastructure return series by transforming listed UK infrastructure returns. The first section deals with some data issues, while the second discusses the transformation process using Fourier analysis as well as how we get the final output. The final part covers the frequency domain representation of the various infrastructure return series.

Data preliminaries

To use Fourier analysis the time series under study must be stationary with zero mean. As we are dealing with return data (i.e., the rate of change) we can be sure of satisfying the first criteria. In order to accomplish the second requirement, we demean the return series but subtracting its sample mean from each observation t from $1,...,T$. Where T is the length of the time series considered. This is highlighted in Figure A1.

Figure A1



As can be seen, the three series display the necessary features of stationarity and zero mean.

Additionally, with ten years of monthly return data T is equal to 128, this is because the use of the DFT requires that the number of observations considered be a power of 2, i.e., $T = 2^n$, hence $128 = 2^7$.

Fourier analysis

Consider a time series $x_0, \dots, x_{T-1}$, we can define its Discrete Fourier Transform as:

$$X_k = \sum_{t=0}^{T-1} x_t e^{\frac{-2\pi i}{T}kt} \qquad \text{...(A1)}$$

with, $k = 0,\ldots,T-1$, e is the natural exponential function (2.71), π is 3.14, and $i = \sqrt{-1}$. This operation transforms the series (x_t), a function of time, into a complex-valued function of frequencies called Fourier coefficients (X_k). It is a decomposition of the variance of the series into the variance of the orthogonal components at each frequency.

Given the Fourier coefficients X_k, we can recover x_t, by using the inverse Discrete Fourier Transform defined as:

$$x_t = \frac{1}{T}\sum_{k=0}^{T-1} X_k e^{\frac{2\pi i}{T}kt} \qquad \ldots\text{(A2)}$$

with, $n = 0,\ldots,T-1$. The inverse Discrete Fourier Transform expresses x_t as a sum of sine and cosine waves with frequency (k/T) cycles per time unit.

Filtering via frequency transformation

Assume our observed time series, x_t is composed of two unobservable components v_t (the underlying series we want) and u_t (equity market noise).

$$x_t = v_t + u_t \qquad \ldots\text{(A3)}$$

We do have some prior ideas about the characteristics of the underlying process we are interested in (v_t) via analysing the frequency characteristics of the Australian unlisted infrastructure series.

Formally, assume that the two components are uncorrelated at all leads and lags, that is:

$$E(v_i u_j) = 0 \,,\ \forall \ i \neq j$$

We now construct a transformation ψ that isolates the underlying series we want v_t from the actual observable x_t series:

$$\hat{v}_t = \sum_{t=0}^{T-1} \psi_k x_{t-k} \qquad \ldots\text{(A4)}$$

The parameters for ψ_k are found from inverting:

$$\psi\left(e^{\frac{2\pi i}{T}kt}\right) = \frac{S_v}{S_v + S_u} = \frac{S_v}{S_x} \qquad \ldots\text{(A5)}$$

where, $$S_\phi = \frac{1}{T}\left|\sum_{t=0}^{T-1} e^{\frac{-2\pi i}{T}kt}\phi_t\right|$$

Note, S_ϕ represents the absolute value of the Fourier coefficients, as defined by equation A1.

Unlisted return series output

Having done the transformation of the listed series, we need to add back an estimate of the mean for the return series (as the Fourier transformation was done on a time series with zero mean). We assume the mean for the estimated unlisted UK infrastructure series is proportional to the mean of the listed UK series multiplied by the ratio of the means of the Australian unlisted and listed infrastructure return series.

Furthermore, as unlisted markets tend to lag that of their listed counterparts, we lag the unlisted UK infrastructure series by six months. This period was chosen based on qualitative assessment of a number of listed and unlisted infrastructure and property markets.

Frequency domain representation

A chart of a return series illustrates how the series changes over time. However, a frequency domain charts illustrates how much of the return series lies within each given frequency band over a range of frequencies.

Figures A2, A3, and A4 illustrate the absolute value of the Fourier coefficients, as described by equation A1, for each of the three return series; Australian unlisted infrastructure, Australian listed infrastructure and UK listed infrastructure.

The bars in each chart refer to an individual cycle (combined sine and cosines) spaced at multiples (i.e., harmonics) of $(1/T)$, which is called the 'fundamental frequency'. Additionally, the cycle's magnitude, as measured by the vertical axis, indicates the relative strength of that cycle in the time series. Bars close to the vertical axis represent low frequencies, while higher and higher frequencies are encountered as we move to the right.

For example, looking at Figure A2, we can see two significant cycles in Australian unlisted infrastructure. The first occurs around once every half year (21/128), while the second occurs approximately every quarter (43/128). These two frequencies could coincide with the period when unlisted infrastructure funds re-value their asset(s), i.e., either once every six months or once every quarter.

We can also see the difference between a series based on transactions (listed) and an appraisal series (unlisted) by comparing the Australian listed and unlisted charts. The size of each cycle per time unit is noticeably smaller for the unlisted series which highlights their relatively stable nature, whereas the listed series has cycles per time unit which are approximately double in size.

Figure A2

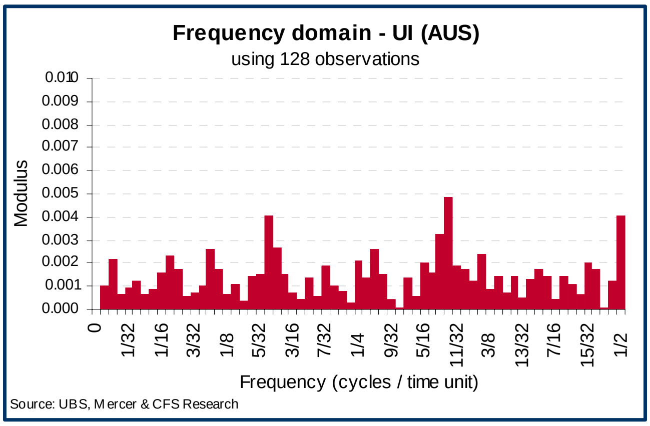


Figure A3

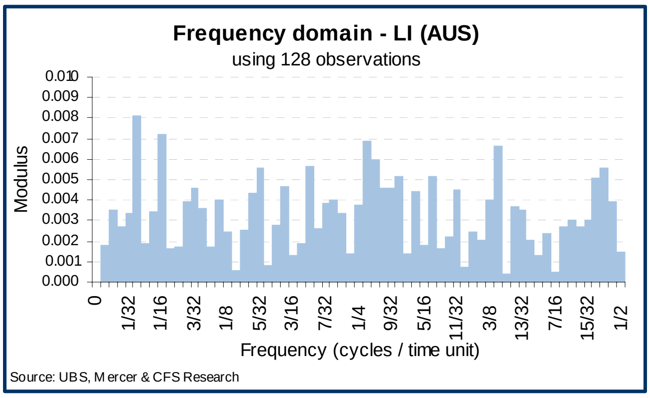
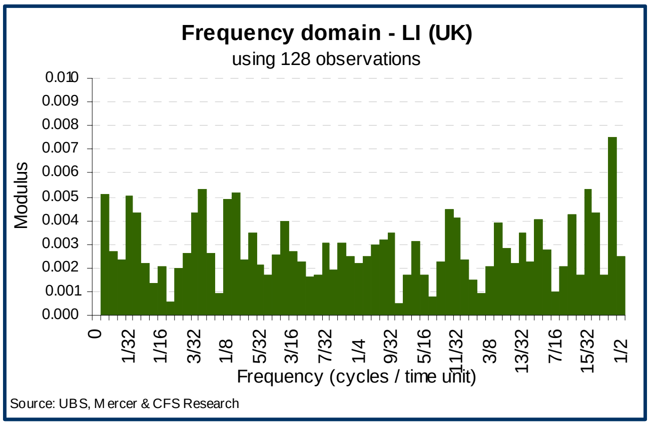


Figure A4



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