INSTITUTIONAL ADVISORY & SOLUTIONS

BUILDING PORTFOLIOS WITH INFRASTRUCTURE

Performance, Cash Flows & Portfolio Allocation

November 2022

AUTHORS

Junying Shen, CFA
Vice President
Co-Head, PGIM IAS Private Assets Research Program
junying.shen@pgim.com
+1 973 508-4538

Frédéric Blanc-Brude, PhD
Director, EDHEC*infra*
frederic.blanc-brude@edhec.edu
+65 6653 8575

The PGIM Institutional Advisory & Solutions (IAS) group provides objective, data-informed analysis to help Chief Investment Officers and Investment Committees manage their portfolios.

To learn more about PGIM IAS, contact IAS@pgim.com or visit pgim.com/IAS.

Institutional portfolios have been increasing allocations to unlisted infrastructure investments. However, to fully understand how infrastructure investments can benefit their portfolios, CIOs need better information on the performance and cash flow characteristics of this asset class, as well as a multi-asset, multi-period portfolio construction framework that is fit-for-purpose when allocating to illiquid, private investments alongside liquid, public investments.

Using asset- and fund-level data, we highlight important differences between infrastructure assets and funds, and compare their historical performance and cash flow characteristics with both public and other private investments. An infrastructure asset's age, sector, business risk and corporate structure all influence the asset's risk-return profile. We examine the sensitivity of infrastructure asset and fund performance to public markets by regressing infrastructure returns (at the aggregate, sector and age group level) on public asset market returns.

We then develop a method to estimate infrastructure equity assets' income returns and cash flows depending on their age and sector. With measures defined that capture both idiosyncratic and time-series income return volatility, we highlight that a CIO cannot ignore the high idiosyncratic risk of infrastructure assets when evaluating their future performance and cash flow risk. To reduce a portfolio's idiosyncratic income return risk, we find that adding assets from the same sector may be as efficacious as adding the same number of assets from different sectors. We show how many assets are needed before idiosyncratic income return risk starts to level off.

To help CIOs make better-informed decisions regarding their allocations to infrastructure, we incorporate our infrastructure cash flow models into PGIM IAS' asset-allocation framework (OASIS). We analyze the performance and liquidity risk of portfolios with different allocations to infrastructure investments and other private assets and demonstrate that infrastructure investments, especially infrastructure assets, could improve portfolio diversification and liquidity, driven by their relatively large and stable income return.

Institutional portfolio allocations to unlisted illiquid infrastructure investments have increased from $167b (December 2010) to $655b (June 2020 – comprising both uncalled dry powder and investment value) – an annualized growth rate of 14%/y.[1] Given the large capital amounts needed for the energy transition and governmental encouragement for institutions to invest for the national welfare, allocations are likely to increase further.

Although infrastructure investments have long been available to institutional investors, data limitations and differences across investment vehicles (*e.g.,* funds versus direct investments) have hindered systematic analysis to help CIOs better understand the portfolio role infrastructure investments can play. Complicating this analysis is that infrastructure investments are usually private and illiquid given their significant investment size, lack of transparency, high search frictions for suitable buyers and sellers and infrequent secondary transaction activities, which raise a number of hurdles for comparing valuation and performance with other public and private assets and for portfolio construction.

Some challenges that unlisted infrastructure poses for CIOs are:

- How to compare infrastructure investment performance consistently with public assets, especially given differences in valuation methodology?
- How to capture the differences in infrastructure investment vehicles (*i.e.,* funds *vs.* assets) and their implications for portfolio performance and liquidity risk?
- How to represent a portfolio's infrastructure exposures to different sectors and ages?
- How to measure the idiosyncratic risk of an undiversified infrastructure portfolio?

Using asset-level and vintage fund-level data, **Section I** reviews the key differences between infrastructure investment vehicles – closed-end funds and direct investments in assets. **Section II** then studies the historical performance of infrastructure investments and compares this with public and other private assets. In addition, we examine the sensitivity of infrastructure assets (equity and debt) and fund returns to public equity and debt market returns.

Recognizing the diversity across infrastructure assets, **Section III** discusses the interconnections among infrastructure sectors, business risks and corporate governance, and their relative impact on historical performance. We highlight how the sensitivities to public equity and debt market returns vary across sectors and ages.

Section IV provides a methodology to model infrastructure assets income returns (and the associated cash flows) utilizing empirical asset-level data. From these data we generate income return volatility measures that CIOs can use to compare the income return properties of infrastructure portfolios of varying sizes, ages and sector exposures.

Finally, in **Section V** we discuss portfolio construction with infrastructure investments. Although common portfolio construction practice relies on mean-variance optimization, this methodology has several shortcomings for portfolios with illiquid assets as it overlooks a key characteristic of such assets – they cannot be used to raise portfolio cash. Unlike periodic fluctuations in returns which tend to have a transitory portfolio impact, insufficient portfolio liquidity can be a matter of survival and must be addressed during portfolio construction.

We employ a cash flow-based portfolio construction framework – OASIS™ – that brings liquidity risk to the fore by modeling private asset cash flows in a manner consistent with a CIO's capital market assumptions.[2] By incorporating infrastructure cash flow modeling into OASIS, a CIO can use the framework to study how various allocations to infrastructure investments interact with other private assets (*e.g.,* private equity and real estate) and impact portfolio performance and liquidity risk. With OASIS, a CIO can integrate their public and private assets into a multi-asset, multi-period portfolio construction process.

1 2021 *Preqin Global Infrastructure Report*.

2 See J. Shen and M. Teng, "Harnessing the Potential of Private Assets: A Framework for Institutional Portfolio Construction," PGIM IAS 2021 and J. Shen, *et al.*, "Asset Allocation and Private Market Investing," *Journal of Portfolio Management,* 2021 47 (4) 71-82.

I. Unlisted Infrastructure Investments – Vehicles and Data

We highlight important differences between unlisted infrastructure assets and funds

- Infrastructure *funds* offer quick access to a potentially diversified portfolio of assets while direct investments in infrastructure *assets* require investors to build their own diversified portfolio over time
- There exists a potential mismatch between the lifespan of a fund and its underlying assets which can impact their relative performance and cash flow characteristics
- Differences in valuation methodologies between funds and assets can affect a CIO's asset allocation decisions – funds rely on GP-reported cash flows and valuations while assets use a "fair market" (*i.e.,* mark-to-market) valuation approach
- To capture distinct features associated with different investment vehicle types, we separately evaluate and model each vehicle's performance and cash flow characteristics

Investors typically make unlisted infrastructure investments using the following vehicles:[3]

- Direct or co-investments in **assets** – buying equity shares or debt tranches of individual infrastructure companies (*i.e.,* assets) *via* a private placement;
- Closed-end investment **funds** with a limited term; and
- Open-end investment **funds** (evergreen structures).

Figure 1 compares closed-end funds ("funds") and direct investments in infrastructure assets ("direct investments" or "assets") – the two most common vehicles for institutional investing in unlisted infrastructure.[4]

Figure 1: Unlisted Infrastructure Investment Vehicles

Closed-end Funds *vs.* Direct Investments in Infrastructure Assets

	Funds	Assets
Features	• Familiar to investors in other alternative assets, such as private equity • Typical fund has a 10-12y term, plus a 2-4y extension period • Covers a full spectrum of strategies (greenfield, brownfield and sector-/region-specific niche strategies) • J-curve effect	• Reduced fees • Better control in establishing portfolio with desired sector/strategy/regional exposure; more flexibility in entering and exiting decisions • Requires in-house resources with considerable expertise in infrastructure assets
Investors	All types of Investors	Public pension funds, government agencies and SWFs compared to other investor types
Investment Performance Metrics	IRR, Multiples (DPI, RPI, TVPI), PME, Net Asset Values	Total Returns, Income Returns, Price Returns
Cash Flow Metrics	Contributions, Distributions	Revenue Growth, Dividend/Revenue Ratio, *etc.*
Data Source	Burgiss	EDHEC*infra*

Source: Burgiss, EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

A closed-end fund is the investment vehicle most familiar to infrastructure investors, offering access to a potentially diversified portfolio of assets (across core, core+ and opportunistic strategies, different sectors and regions) assembled by a general partner (GP). In contrast, direct investments require investors to build their own diversified portfolio over time, but perhaps at lower cost. However, these lower fees must be weighed against the cost of building and maintaining in-house investment expertise, which may explain why the direct investment approach is more commonly used by large pension and sovereign wealth funds.

Another contrast between the fund and direct investment lies in the potential mismatch between the lifespan of the underlying assets and the vehicle. Investors in direct investments can hold assets for as long as they wish – often for a decade or longer. In contrast, a fund's GP may sell assets anytime at their discretion or at the expiration of the fund agreement (say, 10y). This difference in asset holding periods may produce performance differences. Research suggests that the performance and cash flows characteristics of infrastructure funds (with cash flows stemming from early asset sales that are pro-cyclical with the market environment) fail to match those of the underlying infrastructure assets.[5]

3 See Weber *et al.*, 2016.
4 See Probitas Partners, 2018. Appendix A1 shows a comparison table between closed-end and open-end infrastructure funds.
5 See Andonov *et al.,* 2021

For funds we rely on vintage-level cash flow data (pooled across funds of a given vintage) from Burgiss and for direct investments we use asset-level data from EDHEC*infra*. Burgiss aggregates LP-supplied, but GP-reported, *fund* cash flows and valuation data (net of fees and carried interest). EDHEC*infra*, a provider of market indices and valuation analytics, collects reported financial data for unlisted infrastructure equity and debt *assets*. Infrastructure asset data are classified and organized using EDHEC*infra*'s proprietary four-pillar taxonomy (TICCS®). For valuation, EDHEC*infra* uses a "fair market value" (*i.e.,* mark-to-market) approach using discounted future cash flows (*e.g.,* dividends and other shareholder payments), the contemporaneous term structure of interest rates and estimated risk premia.[6]

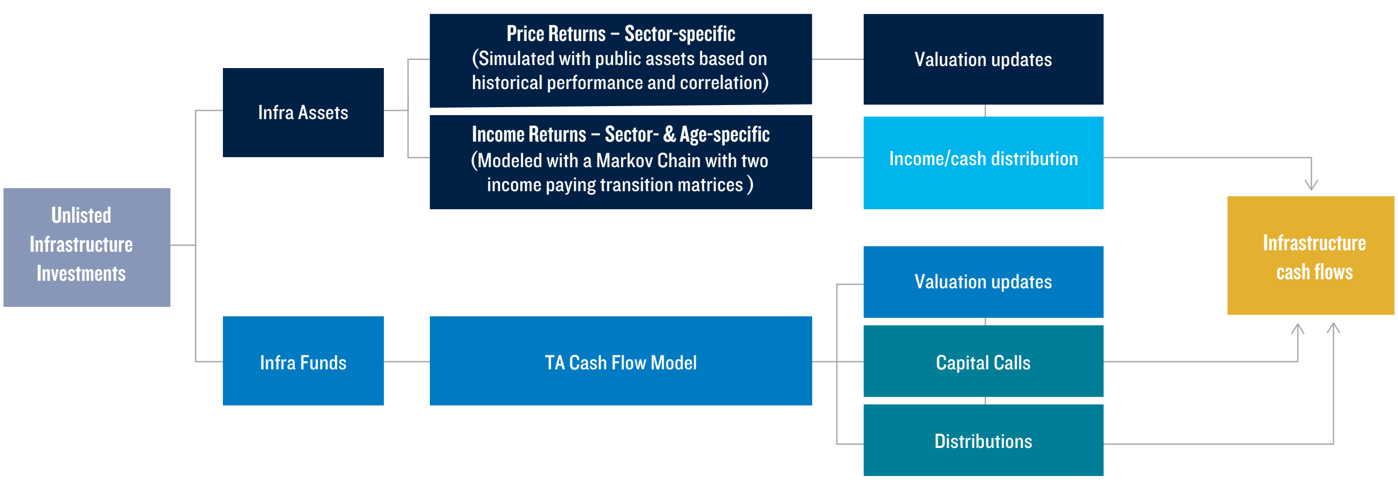
This difference in fund *vs.* asset valuation methodology can cloud a CIO's asset allocation decisions. Fund performance measures (*e.g.,* IRRs, multiples and PMEs) rely on interim GP-reported valuations (or, net asset values – NAVs). This complicates direct performance comparison with assets that use a "fair market value" valuation.[7] As investors know, quarterly IRRs exhibit serial correlation and lag public asset "mark-to-market" valuation changes, particularly when public asset values decline sharply, leading to an increase – "on-paper" – in private asset portfolio allocations (the "denominator effect").[8]

In addition, while interim asset-level "mark-to-market" valuation reflects market gains/losses, interim fund-level valuation includes inflows of further contributions and outflows of distributions from asset dispositions and income, in addition to GP markups/downs of the underlying assets. As a result, unlike an asset, at some point in a fund's life its valuation begins to decline towards zero requiring the CIO to adopt a commitment strategy to maintain a desired portfolio allocation.

Finally, fund cash flows take the form of GP capital calls and distributions. In the early years of a fund's lifespan, the fund generates little or no distributions while investors experience cash outflows in the form of capital calls, investment costs and management fees. Over time, the GP adds value to the acquired portfolio businesses. In the harvesting phase, investors receive cash flow distributions in the form of income and proceeds from investment divestments. As a result, fund investors typically experience a "J-curve" effect pertaining to the fund's net cash flows. In contrast, infrastructure assets are invested upfront and asset cash flows (*i.e.,* dividend income) are relatively stable over the assets' lifespan (on an aggregated basis).

Since institutional investors often use both investment vehicle types for infrastructure investments, we separately model fund-level and asset-level performance and cash flow characteristics (Figure 2) – not only to reflect unlisted infrastructure's unique characteristics compared to other public and private assets, but also to capture distinct features associated with each investment vehicle type. **Sections IV** and **V** discuss our modeling approaches in detail.

Figure 2: Modeling Unlisted Infrastructure Investments



Note: The TA model refers to Takahashi and Alexander, 2002, which is a deterministic model that captures the stylized pattern of limited partner (LP) capital contributions, distributions, and net asset values (NAVs). Source: PGIM IAS. For illustrative purposes only.

6 See Appendix A2 for a brief review of EDHEC*infra*'s Data Collection and Infrastructure Universe Standard and asset pricing methodology.

7 The term "fair market valuation" (FMV) does not imply the entire asset is "transactable" at FMV. FMVs are often based on an end-of-day, end-of-period marginal transaction (*i.e.,* most recent transaction) price which may not reflect the full valuation of the asset.

8 For Q2 2005 to Q4 2021, we examined an AR(1) model for quarterly returns of public assets, EDHEC*infra* infrastructure assets and Burgiss private funds. We regress current returns on lagged returns. An efficient market would tend to have an insignificant coefficient on lag 1 returns suggesting that information is fully incorporated in the current price. We find that both global buyout and infrastructure *funds*, in contrast to public equity returns and infrastructure *asset* returns, demonstrated significant lag1 serial correlation in their quarterly returns.

Index	Lag(1) Coefficient	Lag(1) t-stat
Public Equity (MSCI ACWI)	0.05	0.39
Public Debt (Bloomberg Global Aggregate)	-0.04	-0.34
EDHEC*infra* infra300	0.20	1.63
EDHEC*infra* Infra300 Debt	0.02	0.19
Burgiss Global Buyout Funds	**0.40**	**3.51**
Burgiss Global Infrastructure Funds	**0.29**	**2.48**

Source: Datastream, EDHEC*infra*, Burgiss, PGIM IAS. Provided for illustrative purposes only.

II. Unlisted Infrastructure Investments – Performance & Sensitivity to Public Markets

We compare the historical performance and cash flow characteristics of infrastructure assets and funds with public and other private assets

- Infrastructure asset income returns are a relatively large component of their total returns and are relatively stable with a low correlation to public asset returns
- In contrast to income returns, infrastructure asset price returns are sensitive to public market (equity and debt) total returns
- We model infrastructure asset price returns based on their historical performance and correlation with other public asset returns
- We model infrastructure asset *income returns* and cash flows based on the historical income generating ability of infrastructure assets (including idiosyncratic risk) and not as a function of the public market environment
- For CIOs concerned about liquidity risk, infrastructure assets can serve as an important portfolio cash flow source and diversifier
- Compared to private equity funds, infrastructure funds have similar capital call and valuation profiles, on average, over their lifespan, but generally disburse smaller distributions due to lower NAV growth rates
- We measure the historical sensitivity of infrastructure asset and fund performance to public markets (public equity and debt). Infrastructure assets, both equity and debt at the index level, load significantly on both public equity and bonds. Infrastructure funds load on public equity.
- Both infrastructure assets and funds exhibit performance resilience during periods of volatile public markets

When comparing infrastructure investments with other public and private investments it is important to use returns based on similar valuation methods. Therefore, we first compare the historical performance of infrastructure equity and debt *assets* with public *assets*. Then, we compare infrastructure *funds* with private equity *funds*.

Unlisted Infrastructure Assets *vs.* Public Assets

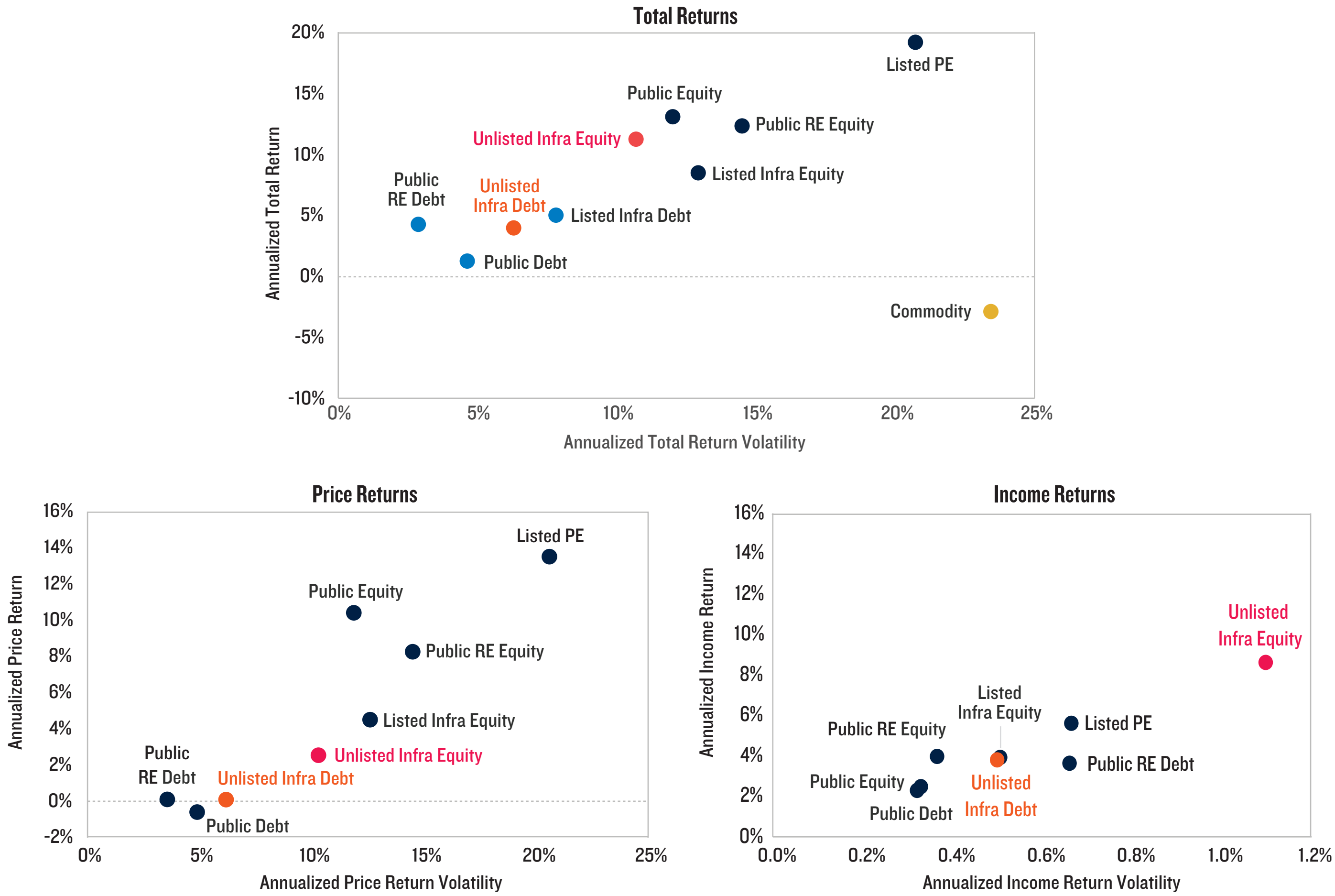
For the past 10y annual *total returns* for infrastructure equity and debt assets were, respectively, roughly comparable to public equity and debt assets (Figure 3). Notably, however, compared to their public asset counterparts, infrastructure equity and debt assets had higher *income returns*. In addition, their annualized income returns (8.6%/y and 3.8%/y for infrastructure equity and debt assets) were a relatively large component of their total returns (11.2%/y and 3.9%/y, respectively).[9] In contrast, the annualized income returns for public equity (2.7%/y) were a small fraction of its total returns (13.0%/y). While the annualized *income return* volatility of infrastructure equity assets (1.1%) is larger than that of public equity (0.3%), it is low in absolute terms and demonstrates income return stability.

Despite infrastructure equity's relatively large and stable income return component, its *total return* volatility can still be large due to its price return volatility. As discussed, a driver of infrastructure equity price returns is the change in the discount factor (term structure of interest rates and estimated risk premia) of future cash flows which is also a driver of equity price returns. So, it is not necessarily unexpected that infrastructure equity and public equity experienced comparable total return volatility, 11% versus 12%, respectively.

Since infrastructure and public equity assets have comparable total returns and volatility, an investor might conclude that both asset types are similar. However, this conclusion might reflect a traditional mean-variance mindset and misses an important distinction of infrastructure equity: its robust and stable income returns. For CIOs concerned about liquidity risk, infrastructure equity can serve as an important portfolio cash flow source.

9 This does not suggest that price return is a small component of unlisted infrastructure asset total return across all sectors. For example, for the past 10y (2012 – 2021) *Transport* infrastructure equity asset has a 13.5%/y annualized total return with 7.2%/y price return and 6.2%/y income return (USD unhedged). **Section III** will discuss the diversity of infrastructure equity assets.

Figure 3: Returns and Volatility, Infrastructure Assets and Public Assets
(2012 – 2021, Annual Returns, USD unhedged, funds excluded)



Note: Public indices: Bloomberg Global Aggregate Total Return Index (public debt), MSCI All Country World Total Return Index (public equity), GSCI Total Return Index (commodity), MSCI World Equity REITS Total Return Index (real estate equity), Bloomberg IG CMBS Total Return Index (commercial real estate debt), S&P Listed Private Equity Index (listed private equity), S&P Global Infrastructure Total Return Index (listed infrastructure equity), DJ Brookfield Infrastructure Corporate Bond Index (listed infrastructure debt), infra300 Index (unlisted Infrastructure equity) and Infra300 Debt Index (unlisted infrastructure debt). Source: EDHEC*infra*, Datastream, PGIM IAS. Provided for illustrative purposes only. An investment cannot be made directly in an index.

Figure 4 shows the correlation of annual *total returns* between infrastructure assets and public assets for 2012-2021. Infrastructure debt had a 0.89 correlation with public debt (and a 0.86 correlation with *listed* infrastructure debt). A relatively high correlation is expected as both the private and public debt valuations are heavily influenced by easily-measured changes in their common term structure exposure. Meanwhile, infrastructure equity demonstrated a moderate total return correlation with public equity (*e.g.,* 0.57 with broad public equity and 0.66 with *listed* infrastructure equity, respectively).[10]

To better understand equity total return correlations, we examine how infrastructure asset income and price returns were correlated with public equity price returns. Figure 5 suggests that the 0.56 *price return* correlation between infrastructure equity assets and public equity closely matched their 0.57 total return correlation – reflecting their common “fair market valuation” approach. In contrast, the correlation between infrastructure equity *income returns* and public equity *price returns* was low (0.19), and lower than the correlation of public equity’s income return with its own price return (0.48). In other words, infrastructure equity’s relatively small price return component of its total return drove its somewhat high total return correlation with public equity.

10 Some investors may use *listed* infrastructure equity as a proxy for unlisted infrastructure assets for asset allocation exercises. However, this may misrepresent unlisted infrastructure assets’ risk and return characteristics. Listed infrastructure assets are more exposed to fluctuations in the public capital markets. For example, management teams of listed investment entities naturally focus on managing their share price in the near term, which may or may not conflict with maximizing longer-term investment asset returns (Weber *et al.,* 2016). Figure 3 also shows the total return correlations between listed infrastructure equity assets (equities of companies engaged in infrastructure and related operations) and public equity was 0.77, compared to 0.57 between unlisted infrastructure equity assets and public equity.

Figure 4: Total Return Correlations

Infrastructure Assets and Public Assets (2012 – 2021 Annual Returns, USD unhedged)

	Public Debt	Public Equity	Comm	Public RE Equity	Public RE Debt	Listed Infra Eq	Listed Infra Debt	Listed PE	Unlisted Infra Eq	Unlisted Infra Debt
Public Debt	1									
Public Equity	0.45	1								
Commodity	-0.06	0.58	1							
Public RE Equity	-0.09	0.41	0.57	1						
Public RE Debt	0.81	0.33	-0.10	0.15	1					
Listed Infra Eq	0.28	0.77	0.61	0.62	0.27	1				
Listed Infra Debt	0.89	0.67	0.21	0.16	0.84	0.59	1			
Listed PE	0.10	0.89	0.80	0.62	0.16	0.79	0.43	1		
Unlisted Infra Eq	0.29	0.57	0.05	0.34	0.32	0.66	0.53	0.39	1	
Unlisted Infra Debt	0.89	0.61	-0.07	-0.06	0.71	0.38	0.86	0.24	0.59	1

Note: Public indices include: Bloomberg Global Aggregate Total Return Index (public debt), MSCI All Country World Total Return Index (public equity), GSCI Total Return Index (commodity), MSCI World Equity REITS Total Return Index (real estate equity), Bloomberg IG CMBS Total Return Index (commercial real estate debt), S&P Listed Private Equity Index (listed private equity), S&P Global Infrastructure Total Return Index (listed infrastructure equity), DJ Brookfield Infrastructure Corporate Bond Index (listed infrastructure debt), infra300 Index (unlisted Infrastructure equity) and Infra300 Debt Index (unlisted infrastructure debt). Source: EDHEC*infra*, Datastream, PGIM IAS. As of 12/31/2021. Provided for illustrative purposes only.

Figure 5: Price & Income Return Correlations

Infrastructure Assets and Public Assets (2012 –2021 Annual Returns, USD unhedged)

		Price Return				
		Public Debt	Public Equity	Listed Infra Eq	Unlisted Infra Eq	Unlisted Infra Debt
Price Return	Public Debt	1				
	Public Equity	0.45	1			
	Listed Infra Eq	0.27	0.77	1		
	Unlisted Infra Eq	0.30	0.56	0.67	1	
	Unlisted Infra Debt	0.90	0.60	0.37	0.57	1
Income Return	Public Debt	-0.07	-0.13	0.08	0.37	0.15
	Public Equity	0.51	0.48	0.48	0.49	0.58
	Listed Infra Eq	0.33	0.47	0.59	0.45	0.47
	Unlisted Infra Eq	-0.22	0.19	0.05	0.30	0.13
	Unlisted Infra Debt	-0.09	0.10	0.14	0.44	0.15

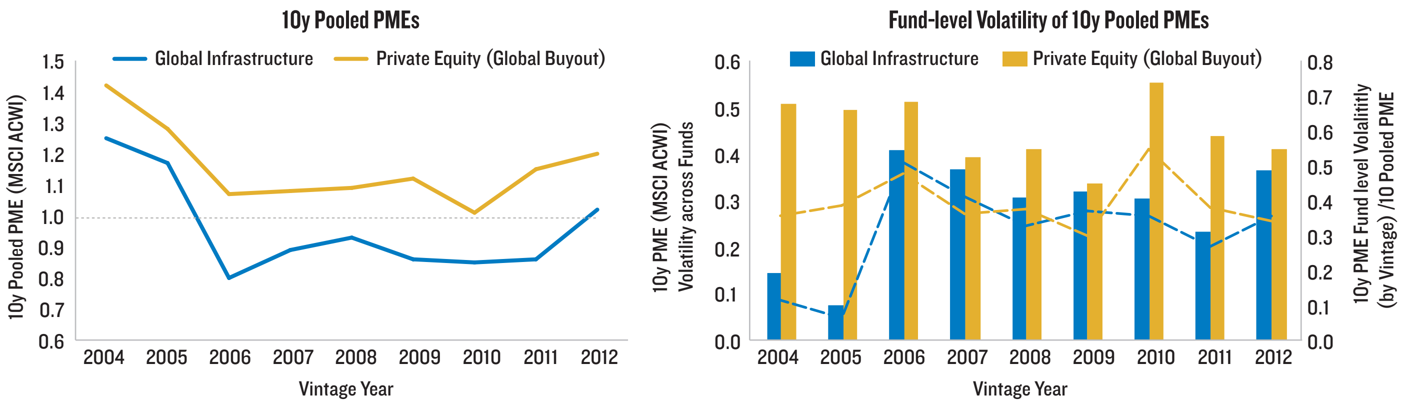
Note: Public indices: Bloomberg Global Aggregate Total Return Index (public debt), MSCI All Country World Total Return Index (public equity), S&P Global Infrastructure Total Return Index (listed infrastructure equity), infra300 Index (unlisted infrastructure equity) and Infra300 Debt Index (unlisted infrastructure debt). Since income returns of infra300 Index and Infra300 Debt Index are only available on an annual basis since year 2012; the correlation calculation in this figure is based on 10y income returns and price returns from 2012 to 2021. Source: EDHEC*infra*, Datastream, PGIM IAS. As of 12/31/2021. Provided for illustrative purposes only.

Figures 4 and 5 motivate our decision to model infrastructure asset price and income returns separately. Specifically, we model infrastructure asset *price returns* based on their historical performance and correlation with other public asset returns. In contrast, we model infrastructure asset *income returns* based on the historical income generating ability of infrastructure assets (including idiosyncratic risk) and not as a function of the public market environment. **Section IV** presents these modeling details.

Unlisted Infrastructure Funds *vs.* Other Private Asset Funds

Figure 6 shows the 10y pooled PME (benchmarked by MSCI ACWI total return index) of global infrastructure and global buyout funds for vintages from 2004 to 2012.[11] In general, infrastructure funds had lower PME performance than buyout funds (0.96 average 10y PME for infrastructure funds *vs.* 1.16 for buyout funds). Figure 6 also shows the cross-sectional fund-level volatility of 10y PMEs of infrastructure and buyout funds. Infrastructure fund-level PME volatility (columns) was generally lower than that of private equity. However, if scaled by the 10y pooled PME (except for 2004 and 2005 vintages in which only five infrastructure funds exist in Burgiss) the relative cross-sectional PME volatility (dashed lines) of infrastructure and buyout funds were comparable.

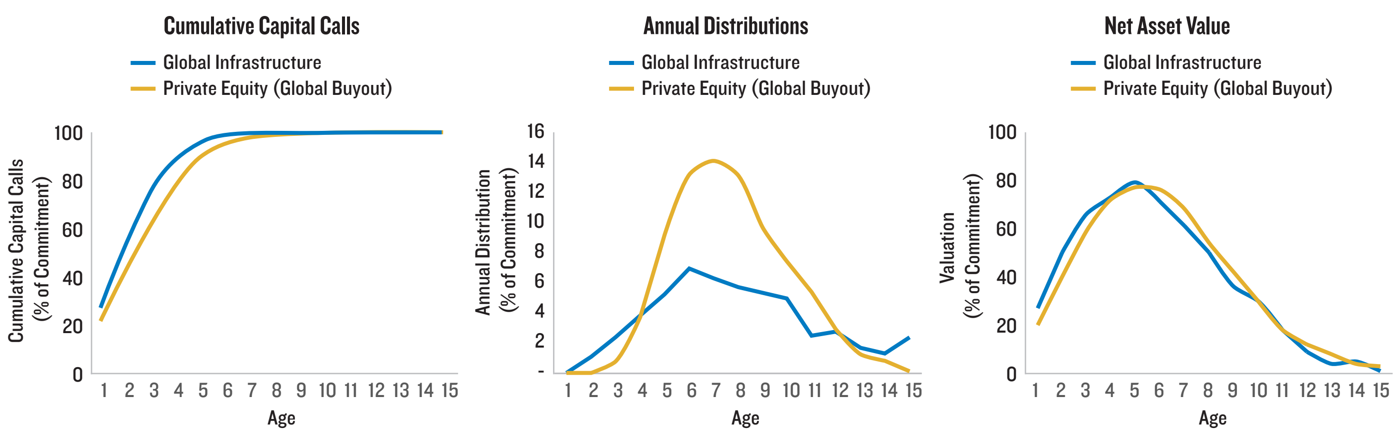
Figure 6: 10y Pooled PMEs and Fund-level Dispersion, by Vintage
(Global Infrastructure & Buyout Funds)



Source: Burgiss, PGIM IAS. As of 3/31/2022. Provided for illustrative purposes only.

Figure 7 shows the 50th percentile cash flow and valuation profiles of global infrastructure and global buyout funds.[12] Although the median cumulative *capital calls* are comparable, the median annual *distributions* of infrastructure funds are much lower than that of buyout funds, indicating **infrastructure's lower valuation growth rate.**[13] This is consistent with the comparable *valuation profiles* between the two types of private asset funds – a relatively slower growing infrastructure NAV with lower distribution amounts (income and disposals) paid out. As a reminder, cash flow interpretations are subject to investment vehicles – funds *vs.* assets – due to their different nature (asset dispositions and income for the former *vs.* dividend income for the latter).

Figure 7: Cash Flow and Valuation Profile Comparison, by Age
(Global Infrastructure & Buyout Funds)



Source: Burgiss, PGIM IAS. As of 3/31/2022. Provided for illustrative purposes only.

11 Burgiss defines infrastructure funds as comprised of long-lived assets, properties or other structures that provide some type of essential product or service which generate investment returns through income. They are infrastructure equity funds.

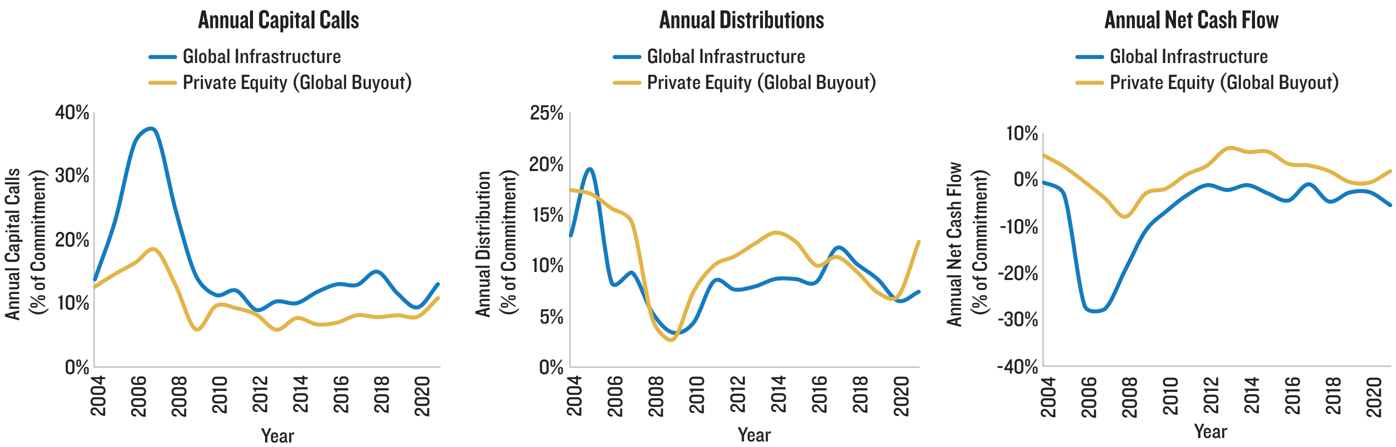
12 Burgiss allows users to examine the performance and cash flow behavior of a selected set of funds over their lifespan. The dispersion of results is presented by five percentile groupings 5%, 25%, 50%, 75% and 95%. For example, the 50%-percentile contribution profile of global buyout represents the median contribution amount (scaled by individual funds' commitment amounts) of global buyout funds at given ages.

13 In Appendix A6, we show that the *rate* of distribution (*i.e.,* the % of contemporaneous NAV paid out as distribution) is similar for buyout and infrastructure funds.

In contrast to infrastructure assets for which we model price and income returns, we model cash flows of infrastructure funds using the TA cash flow model with specifically calibrated parameters, similar to the method for modeling PE fund cash flows.[14] **Section V** and Appendix A6 provide details.

Figure 8 compares vintage-pooled annual cash flows of global infrastructure and buyout funds, by calendar year. "Vintage-pooled" means annual cash flows of funds across different vintages (*i.e.,* different ages) are aggregated at the time of evaluation. For example, during 2021, 7.4% of global infrastructure funds' aggregated commitments were distributed (which can consist of zero from recent vintage funds to well above 7.4% from more seasoned funds). Figure 8 shows the annual distributions of global infrastructure funds tracked those of global buyout funds with both demonstrating dips around the GFC and global pandemic. Annual capital calls of global infrastructure funds were historically higher than buyout funds, and, as a result, the annual *net* cash flows of global infrastructure funds were lower historically than buyout funds.[15]

Figure 8: Vintage-Pooled Annual Cash Flow Comparison, by Calendar Year
(Global Infrastructure & Buyout Funds)



Source: Burgiss, PGIM IAS. As of 3/31/2022. Provided for illustrative purposes only.

Unlisted Infrastructure Assets & Funds – Performance Sensitivity to Public Markets

To examine the sensitivity of infrastructure asset and fund performance to public markets, we regress infrastructure infra300 index-level (equity and debt) asset annual total returns and fund vintage-level IRRs on public market (equity and debt) annual total returns.[16] We include a "Pre-2015" dummy variable as a regressor to control for any secular trend in infrastructure valuation premium prior to 2015 to account for persistent excess demand for this asset class as it became more popular and institutionalized.[17] Figure 9 shows the adj-R^2 of infrastructure funds was only 25%, compared to 61% for infrastructure equity and 68% of infrastructure debt assets. This difference in explanatory power is not surprising given the difference in valuation approach between funds and public markets.

Both infrastructure equity and debt assets show significant betas for public debt and public equity, with larger coefficients for infrastructure equity compared to infrastructure debt. We also find a significant public equity coefficient for infrastructure funds, but it is the lowest among the three infrastructure vehicle types. Finally, the "Pre-2015" dummy is significant and positive for infrastructure equity assets, indicating higher infrastructure equity asset performance pre-2015.[18]

14 The TA model refers to Takahashi and Alexander, 2002, which is a deterministic model that captures the stylized pattern of limited partner (LP) capital contributions, distributions, and net asset values (NAVs).

15 As of December 2007, Burgiss reported cash flows for 41 global infrastructure funds compared with 969 global buyout funds. 28 of the 41 global infrastructure funds were 3y old or less (*i.e.,* vintage 2004 and later). The hump in the annual capital calls of global infrastructure funds from 2005 to 2008 could be a result of the fund pool consisting mainly of new funds that were calling capital heavily during their early years. The "hump" effect dissipated as the global infrastructure fund pool gradually included more seasoned funds.

16 We use infra300 Index when we evaluate the performance of infrastructure equity at the aggregate level. To evaluate infrastructure equity performance by categories including sectors, age groups, business risks, corporate structures and thematic strategies (**Section III**) and the associated income return and cash flow modeling (**Section IV**), we use EDHEC*infra*'s Broadmarket Unlisted Infrastructure Equity Index family. The constituents of infra300 Index are a subset of the constituents of the Global Broadmarket Unlisted Infrastructure Equity Index.

17 See F. Blanc-Brude, A. Gupta, L. Lu, and A. Wee, "The Volatility of Unlisted Infrastructure Investments: Valuation Drivers and Trends, 2000-2021," 2021, EDHEC*infra*.

18 In Appendix A4 we show OLS regression analysis with quarterly total return during the same 2006-2021 period.

Figure 9: Infrastructure *vs.* Public Assets Annual Total Returns; OLS Regression
(2006 – 2021; Annual Returns, USD unhedged)

Annual Total Return	Constant	Public Debt (10y US Treasury)	Public Equity (MSCI ACWI)	Pre-2015 Dummy
Dependent Variable	Infrastructure Equity Asset (infra300 Index)			
adj-R^2	61%			
coefficient	-0.03	0.65	0.59	0.12
t-stat	-0.68	1.96	4.00	2.94
p-value	51%	7%	0%	1%

Annual Total Return	Constant	Public Debt (10y US Treasury)	Public Equity (MSCI ACWI)	Pre-2015 Dummy
Dependent Variable	Infrastructure Debt Asset (Infra300 Debt Index)			
adj-R^2	68%			
coefficient	-0.03	0.45	0.43	0.03
t-stat	-1.65	2.56	5.52	1.52
p-value	12%	2%	0%	15%

Annual Total Return	Constant	Public Debt (10y US Treasury)	Public Equity (MSCI ACWI)	Pre-2015 Dummy
Dependent Variable	Infrastructure Fund IRR			
adj-R^2	25%			
coefficient	0.05	0.10	0.36	-0.01
t-stat	1.27	0.29	2.31	-0.21
p-value	23%	78%	4%	84%

Note: We use Burgiss reported quarterly IRRs (net of fees, USD unhedged) to represent the periodic total returns of private asset LP performance. Indices shown in the figure include: S&P US Treasury Bond Current 10y Index, MSCI All Country World Total Return Index, infra300 Index and Infra300 Debt Index. All returns are USD unhedged. Source: EDHEC*infra*, Datastream, Burgiss, PGIM IAS. Provided for illustrative purposes only.

Finally, we examine how infrastructure funds and assets perform during volatile public market periods. Figure 10 shows the average cumulative performance of public markets, private asset investments and infrastructure investments before, during and after seven equity VIX spike events.[19]

During a quarter of sharply higher public equity market volatility, both infrastructure funds and assets exhibited **resilience**. Compared to US public equity (S&P 500) and high yield credit that, on average, declined about 9.6% and 5.5%, respectively, in the quarter in which market volatility spiked, infrastructure equity assets *rose* 2.4% while infrastructure debt assets and funds both lost only about 1%. In addition, infrastructure equity assets' cumulative performance over the entire – pre-spike, spike and post-spike – period (45.9%) ranked between global private equity funds (53.6%) and public equity (38.7%).

19 The month during which the average daily VIX index value increases significantly (by at least 50% compared to the average VIX level two months earlier) is labeled the "spike month." The calendar quarter in which the spike month resides is labeled the corresponding "spike quarter." See Shen, 2020.

Figure 10: Total Cumulative Quarterly Returns (Pre-Spike, Spike and Post-Spike Periods)
(Q4 2005 – Q4 2021, 7 VIX Spike Events, USD unhedged)

Asset Class	Total Cumulative Returns			
	Pre-Spike (7 Quarters)	Spike Quarter (1 Quarter)	Post-Spike (7 Quarters)	Entire Period (15 Quarters)
S&P 500	17.8%	-9.6%	30.2%	38.7%
10y Treasury	7.6%	6.2%	5.2%	20.3%
US HY Credit	14.7%	-5.5%	23.0%	33.3%
US IG Credit	8.8%	1.1%	12.6%	23.8%
Global Buyout LP	28.7%	-3.8%	24.0%	53.6%
Global Mezzanine LP	16.8%	-0.9%	13.6%	31.5%
Global Real Estate LP	10.5%	0.8%	4.2%	16.1%
Global Infrastructure LP	15.1%	-1.8%	10.8%	25.3%
Infrastructure Equity Assets	25.7%	2.4%	13.4%	45.9%
Infrastructure Debt Assets	6.9%	-0.9%	9.7%	16.1%

Note: We use Burgiss reported quarterly IRRs (net of fees, USD unhedged) to represent the periodic total returns of private fund performance (Global Buyout LP, Global Mezzanine LP and Global Infrastructure LP). We use the NFI-ODCE Open-End, Capitalization-Weighted Index available from ODCE for real estate quarterly total returns (net of fees, USD unhedged). We use the infra300 Index from EDHEC*infra* to represent the quarterly total returns of infrastructure equity assets and the Infra300 Debt Index to represent the quarterly total returns of infrastructure debt assets. Source: EDHEC*infra*, Datastream, Burgiss, ODCE, FRB St. Louis (FRED), PGIM IAS. Provided for illustrative purposes only. An investment cannot be made directly in an index.

III. Diversity of Infrastructure Equity Assets – Sector Risk, Performance & Public Market Sensitivity

We investigate the sector, business and corporate structure risks of infrastructure assets and how their interconnections drive risk-return profiles

An unlisted infrastructure asset's sector, business risk and corporate structure have ramifications for its risk-return profile:

- **Contracted** assets pay a fixed income over a contracted term and demonstrate lower income risk
- **Merchant** assets have income that depends on user demand while **Regulated** assets operate to impose a reasonable cost to end users – both show higher income risk than **Contracted** assets
- There is a wide variation in infrastructure asset-level performance within a given sector, reflecting high idiosyncratic risk
- We measure the sensitivity of infrastructure equity assets, by sector, to public markets. Many sector-level coefficients on public equity are significant. Only *Social Infrastructure* has a significant public debt beta.

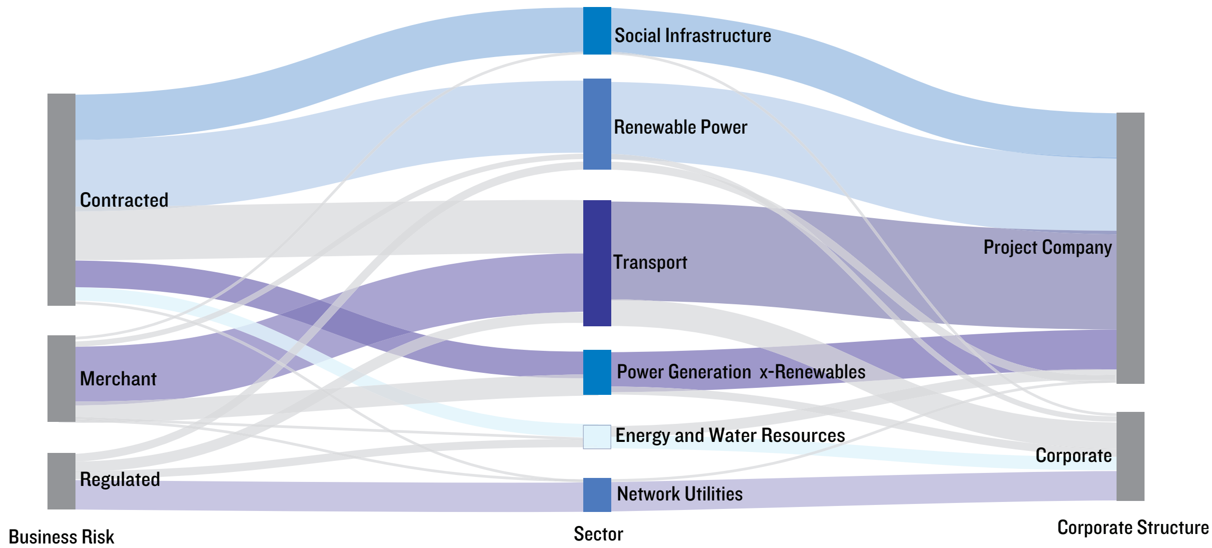
We have presented the historical performance of unlisted infrastructure assets at the broad asset class level. However, the risk-return profile of an infrastructure equity asset depends, in large part, on the asset's sector, business risk, age/maturity, thematic strategy and corporate structure exposures. [20] Using EDHEC*infra*'s **Global Broadmarket Unlisted Infrastructure Equity Index** (equally-weighted) as representative of the global infrastructure asset universe, Figure 11 shows how infrastructure sectors are interconnected by business risks and corporate structures.[21]

20 As Europe represents close to 70% of the regional exposure of EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Index, "Region" is not included in Figure 11 and subsequent analysis. Appendix A5 shows the risk-return profile of the EDHEC*infra* Regional Unlisted Infrastructure Equity Index (equally-weighted, USD unhedged).

21 We also study the interconnections for the EDHEC*infra* Broadmarket Infrastructure Equity value-weighted index which are like those for the equally-weighted index.

Figure 11: Interconnections of Business Risk, Corporate Structure and Sector

(EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Index; equally-weighted; USD unhedged)



Note: We exclude *Data Infrastructure* and *Environment Services* from the list of sectors presented due to limited data. Source: EDHEC*infra*, PGIM IAS. As of Q3 2021. Provided for illustrative purposes only.

Assets in the *Social Infrastructure*, *Renewable Power* and *Power Generation x-Renewables* sectors are generally contracted project assets from which the asset owner receives a fixed payout (income) at regular intervals based on specific service level agreements. In contrast, almost half of the assets in the *Transport* sector are exposed to Merchant risk meaning that the income stream depends on future user demand which may be volatile. Finally, almost all *Network Utilities* assets, typically natural monopoly assets, are regulated to ensure operations at a reasonable cost to end users.[22]

Figure 12 shows the 10y annualized total returns, price returns and income returns and their volatilities for the Broadmarket Unlisted Infrastructure Equity indices by sector, business risk and thematic strategies – *Core*, *Core+* and *Opportunistic*.[23] As expected, *Contracted* equity assets demonstrated lower income risk than *Merchant* and *Regulated*. *Project Companies*' historical price return was higher than infrastructure *Corporates*, partly driven by higher leverage.

The conventional *Power Generation x-Renewable* sector is very mature with low historical price returns. However, it paid high dividends relative to price, contributing to rather high income returns. *Transport,* largely exposed to *Merchant* risk, showed high price return risk as did *Energy and Water Resources* (mainly pipeline, energy resource processing and storage companies).

Figure 12 also includes the risk-return profile of infrastructure thematic strategies from *Core* to *Opportunistic*. The apparent linear total (and price) risk-return trend across the strategies, is generally by construction as EDHEC*infra*'s thematic strategy classification is based on an asset's expected return quartile. *Opportunistic,* with a heavy concentration of *Merchant* relative to the *Core* and *Core+* strategies, showed the highest annualized total return and price return, along with the highest volatility.[24] Notably, the infrastructure thematic strategies had comparable *income* risk-return profiles.

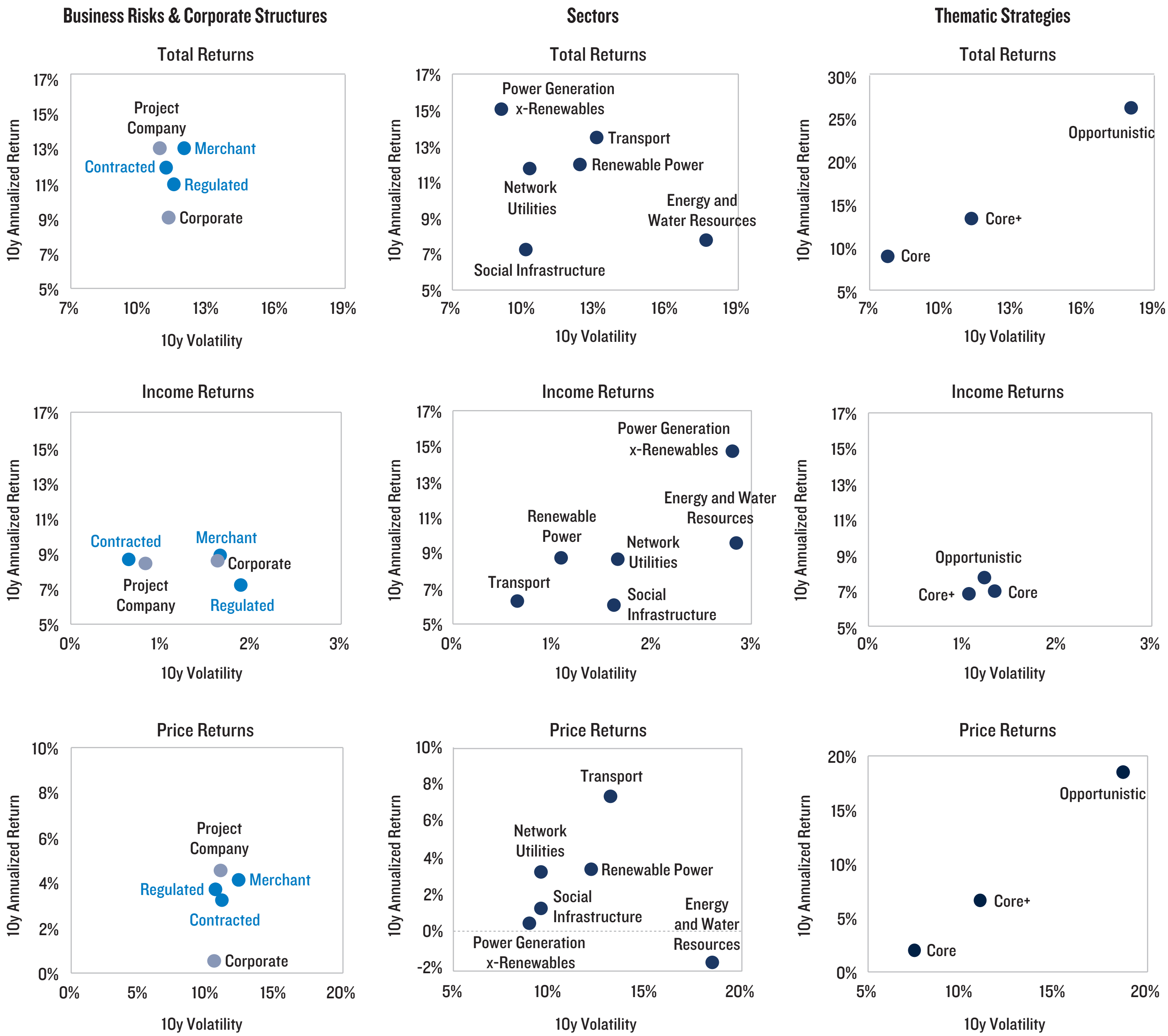
22 EDHEC*infra*, "The Infrastructure Company Classification Standard," EDHEC Infrastructure Institute, 2022.

23 For details see Appendix A3. The terminology regarding thematic strategies (*Core*, *Core+* and *Opportunistic*) is inherited from real estate market practice.

24 Appendix A7 reviews a breakdown of sectors and business risks of EDHEC*infra*'s *Core/Core+/Opportunistic* thematic strategy indices.

Figure 12: Infrastructure Equity Risk & Return, by Business Risk/Corporate Structure/Sector/Thematic Strategy

(EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Annual Returns; USD unhedged)



Note: Each dot represents the 10y annualized total/price/income return and volatility of the Broadmarket Unlisted Infrastructure Equity indices (equally-weighted, USD unhedged). Period 2012 to 2021. Source: PGIM IAS, EDHEC*infra*. Provided for illustrative purposes only. An investment cannot be made directly in an index.

Figure 13 shows the correlation of annual total returns, price returns, and income returns of the Broadmarket Unlisted Infrastructure Equity sector indices over the last 10y. Although sector total returns and price returns were moderately to highly correlated with each other, the correlation of sector-level income returns was not (*e.g.*, the income return correlation between *Power Generation x-Renewables* and *Renewable Power* was -0.35, while the income return correlation between *Network Utilities* and *Transport* was 0.11). Therefore, to capture the potential cash flow diversification from investing in multiple sectors, it is important to model infrastructure asset cash flows at the sector level.

Figure 13: Infrastructure Equity Sector Return Correlations

(EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Index Annual Returns; equally-weighted; USD unhedged)

	Power Generation x-Renewables	Social Infra.	Energy and Water Resources	Transport	Renewable Power	Network Utilities
			Total Return			
Power Generation x-Renewables	1					
Social Infra.	0.50	1				
Energy and Water Resources	0.40	0.75	1			
Transport	0.75	0.63	0.70	1		
Renewable Power	0.58	0.78	0.73	0.85	1	
Network Utilities	0.73	0.68	0.68	0.96	0.86	1
			Price Return			
Power Generation x-Renewables	1					
Social Infra.	0.44	1				
Energy and Water Resources	0.30	0.72	1			
Transport	0.72	0.67	0.68	1		
Renewable Power	0.58	0.83	0.73	0.87	1	
Network Utilities	0.75	0.71	0.59	0.95	0.85	1
			Income Return			
Power Generation x-Renewables	1					
Social Infra.	0.66	1				
Energy and Water Resources	-0.22	-0.50	1			
Transport	0.41	0.20	-0.04	1		
Renewable Power	-0.35	-0.09	0.52	0.21	1	
Network Utilities	0.16	0.23	0.13	0.11	0.18	1

Note: Period 2012 to 2021. Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

We examine the total return sensitivity of infrastructure equity assets, by sector, to public assets (equity and debt). Figure 14 shows the regression results using the same independent variables as in Figure 9. Most of the sector-level coefficients on public debt are *not* significant, except for a significant public debt beta for *Social Infrastructure* (1.32) – mostly contracted project assets. Consistent with the regression analysis for infrastructure equity at the aggregate level, most of the sector-level coefficients on public equity are significant, with adj-R^2s ranging from 0.28 to 0.72. Overall, the results suggest a diversification potential from investing in infrastructure assets along with public assets.

Figure 14: Infrastructure Equity Asset Sectors *vs.* Public Assets Annual Total Returns; OLS Regression

(2006 – 2021, Annual Returns, USD unhedged)

Annual Total Return	Constant	Public Debt (10y Treasury)	Public Equity (MSCI ACWI)	Pre-2015?
Dependent Variable	Power Generation x-Renewables			
adj-R^2	28%			
coefficient	0.09	0.25	$\boxed{0.46}$	0.07
t-stat	1.70	0.58	2.40	1.37
p-value	11%	57%	3%	19%

Annual Total Return	Constant	Public Debt (10y Treasury)	Public Equity (MSCI ACWI)	Pre-2015?
Dependent Variable	Social Infrastructure			
adj-R^2	52%			
coefficient	-0.08	$\boxed{1.32}$	$\boxed{0.73}$	0.11
t-stat	-1.41	2.89	3.62	1.99
p-value	18%	1%	0%	7%

Annual Total Return	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Renewable Power			
adj-R^2	57%			
coefficient	0.00	0.47	0.38	$\boxed{0.15}$
t-stat	0.05	1.46	2.06	3.39
p-value	96%	18%	7%	1%

	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Energy and Water Resources			
adj-R^2	73%			
coefficient	-0.06	0.84	0.25	$\boxed{0.31}$
t-stat	-1.15	1.91	1.00	5.30
p-value	28%	9%	34%	0%

Annual Total Return	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Transport			
adj-R^2	44%			
coefficient	-0.01	0.69	$\boxed{0.59}$	0.10
t-stat	-0.20	1.69	3.27	1.87
p-value	84%	12%	1%	9%

Annual Total Return	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Network Utilities			
adj-R^2	44%			
coefficient	-0.02	0.62	$\boxed{0.63}$	0.11
t-stat	-0.38	1.39	3.18	1.99
p-value	71%	19%	1%	7%

Note: Infrastructure sector indices shown in the figure are the Broadmarket Unlisted Infrastructure Equity Sector Index (equally-weighted). Since the start date of the *Renewable Power* Index and *Energy and Water Resouces* Index is Q3 2008 and Q1 2008, respectively, their regressions are for 2009 to 2021. Public indices: S&P US Treasury Bond Current 10y Index and MSCI All Country World Total Return Index. All returns are USD unhedged. Source: EDHEC*infra*, Datastream, Burgiss, PGIM IAS. Provided for illustrative purposes only.

We also examine the performance sensitivity of infrastructure equity assets, by age groups, to public assets. Infrastructure equity assets with an age between 0-10y represent greenfield and operating assets. The regression analysis (Figure 15) shows a significant public equity beta but not a significant public debt beta, suggesting a growth-like attribute for immature assets. However, for infrastructure equity assets with age greater than 10y, representing brownfield and mature assets which are expected to generate relatively stable income, both public equity and public debt betas are significant. In addition, the adj-R^2 of infrastructure equity assets with age 10y+ (64%) is higher than those with age 0-10y (47%), indicating performance more aligned with public markets as assets mature.

Figure 15: Infrastructure Equity Asset Age Groups *vs.* Public Assets Annual Total Returns; OLS Regression
(2006 – 2021, Annual Returns, USD unhedged)

Annual Total Return	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Age 0-10y			
adj-R^2	47%			
coefficient	0.01	0.59	$\boxed{0.59}$	$\boxed{0.12}$
t-stat	0.16	1.46	3.24	2.25
p-value	87%	17%	1%	4%

Annual Total Return	Constant	Public Debt	Public Equity	Pre-2015?
Dependent Variable	Age 10y+			
adj-R^2	64%			
coefficient	-0.02	$\boxed{0.70}$	$\boxed{0.58}$	$\boxed{0.11}$
t-stat	-0.64	2.42	4.51	2.89
p-value	54%	3%	0%	1%

Note: Infrastructure age bucket indices shown in the figure are the Broadmarket Unlisted Infrastructure Equity Age Bucket Index (equally-weighted). Public Indices: S&P US Treasury Bond Current 10y Index and MSCI All Country World Total Return Index. All returns are USD unhedged. Source: EDHEC*infra*, Datastream, Burgiss, PGIM IAS. Provided for illustrative purposes only.

Idiosyncratic Risk

Within a sector, there is also wide variation in infrastructure asset-level performance. Figure 16 shows the mean, median and standard deviation of asset-level annualized income returns, by sector. Median income returns were lower than the means, indicating positive skewness of income returns within a sector. In addition, we note the high standard deviation of annualized income returns across assets within a sector (*e.g.,* the cross-sectional income return volatility for *Renewable Power* assets was 10.8% with a range of annualized income returns of more than 30 percentage points).

Since a CIO cannot invest in a single asset that gives diversified sector exposure, the CIO cannot safely ignore this high degree of asset-level idiosyncratic income return risk when constructing portfolios with few infrastructure assets. Consequently, to properly analyze the income return risk of a CIO's asset allocation with prospective asset investments, the asset-level idiosyncratic risk must be incorporated.[25]

Figure 16: Annualized Income Returns, by Sector, Summary Statistics
Infrastructure Equity Assets

Sector	Mean	Median	Std Deviation
Power Generation x-Renewables	9.1%/y	5.6%/y	10.8%/y
Social Infrastructure	6.0%	5.1%	5.9%
Energy and Water Resources	7.3%	5.1%	8.6%
Transport	4.7%	1.8%	7.4%
Renewable Power	7.6%	3.8%	9.6%
Network Utilities	7.3%	5.2%	8.0%

Note: The table does not control for age groups or regional exposures of infrastructure assets, *i.e.*, the summary statistics (*e.g.*, mean, median, standard deviation) describe annualized income return of assets in the same sector with different ages and from different regions. More details to follow in **Section V.2** Modelling Income Return of Individual Infrastructure Asset. Underlying income returns are from 690 firms in EDHEC*infra* database from Q1 2000 to Q2 2021. We exclude *Data Infrastructure* and *Environment Services* for consistency with the previous figures. Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

25 In like fashion, OASIS includes fund-level idiosyncratic risk for CIOs who hold relatively few funds.

IV. Modeling Infrastructure Asset Price & Income Returns

We use a 3-step process to estimate an infrastructure asset's income return over the investor's investment horizon based on the asset's age, sector exposure and income-paying behavior

- We define an income return volatility measure that combines both **time-series** volatility and **cross-sectional** (*i.e.,* idiosyncratic) volatility
- We quantify the relative **diversification benefits** of either increasing the **number of assets** in an infrastructure portfolio or increasing the **number of sector exposures**
- To reduce the portfolio's idiosyncratic risk, we find that adding assets from the same sector may be as efficacious as adding the same number of assets from different sectors
- While portfolio idiosyncratic income return risk falls as the number of assets (of a given sector) increases, we show that about seven assets are needed before **idiosyncratic income return risk** starts to level off
- We differentiate income return modeling between **existing** and **prospective** infrastructure asset investments

Recall that infrastructure equity asset price returns were moderately correlated (0.56) with public asset price returns, whereas the income return correlation between infrastructure equity assets and public assets was muted (0.19), reflecting the low sensitivity of infrastructure income returns to public market fluctuations. Therefore, we model infrastructure asset price and income returns separately.

We proxy an infrastructure asset's quarterly **price return** by its sector's quarterly price returns sampled from one of two multivariate distributions (one for a "good" economic state and the other for a "bad" state). The two multivariate distributions are each fitted based on the empirical joint distribution of historical price returns for sector-level infrastructure and total returns for public assets. As a result, the sampled price returns of infrastructure equity capture the infrastructure *sector's* historical exposure to public market total returns.[26]

In contrast, an infrastructure asset's quarterly **income return** depends on its age, sector and idiosyncratic behavior.[27] Intuitively, if an asset had a non-zero income return last period then it is more likely than not to have a non-zero income return this period. In addition, if the asset has a positive income return during this period, the level of income return is likely to be highly correlated with the prior period's level of income return. We therefore use a Markov modeling approach whereby an infrastructure asset's expected quarterly income return depends only on the asset's prior period income return which captures the "path-dependency" nature of an asset's dividend payout behavior.

There are three steps to estimate an infrastructure asset's future quarterly income return:

Step 1: Determine **if** dividend income is paid or not, at each quarter over the asset's lifetime;

Step 2: If income is paid in a quarter, determine **the quartile** of the sector-specific income return distribution from which to draw the quarterly income return; and

Step 3: If income is paid in a quarter, randomly draw the quarterly income return from the appropriate quartile selected in Step 2.

This process involves two "transition matrices" that describe an asset's income paying behavior *every period*, based on the asset's income paying behavior in the *preceding period*. The first transition matrix (Step 1) determines if an asset will pay a dividend this period whereas the second transition matrix (Step 2) determines the magnitude of the asset's income return this period. Both transition matrices are estimated using data from 690 assets in EDHEC*infra*'s database from Q1 2000 to Q2 2021.

To simplify the discussion, we illustrate the three steps of the income return generation process using an annual frequency rather than quarterly (which OASIS uses). However, for the study of income return volatility and portfolio construction implications in the next section, we model and estimate quarterly income returns.[28]

Step 1: Figure 17 shows the annual **Zero** *vs.* **Non-zero Income Paying State Transition Matrix**. There is a separate matrix for each age group – *Greenfield, Operating, Brownfield* and *Mature*. However, based on historical data, we do not find the transition probabilities depend on the economy, nor are they much different across sectors. The cells are the probabilities of transitioning from a preceding year's income paying state (indicated by row) to either Zero or Non-zero income paying state in the current year (column). For example, if a 7y-old *Operating* infrastructure asset paid income during the prior year, there is a 92% probability that it will pay income this year (see red circle) and an 8% probability it pays zero income.

26 See Appendix A9 for details on public and private market simulation and the definition of economic state. Each asset is fitted as a t-distribution with degrees of freedom parameterized respectively based on their empirical distribution of historical returns of either "good" or "bad" economic state. The dependance structure of each multivariate distribution is captured through a Gaussian copula reflecting the empirical correlation of assets returns.

27 We identify sector and age as the two dimensions that affect infrastructure income return characteristics. Other dimensions such as business risks and corporate structures are closely related to sector (Figure 11) and so do not provide much additional information to model income return characteristics. Income return modelling based on further granularity (*e.g.*, sub-sectors) is subject to data limitations.

28 To generate quarterly income return, we convert the annual transition probabilities to quarterly.

Figure 17: Annual Zero *vs.* Non-zero Income Paying State Transition Matrix (by Age Group)

Age Group	Greenfield (<5y)		Operating (6-10y)		Brownfield (11-20y)		Mature (>20y)	
from \ to	Non-zero	Zero	Non-zero	Zero	Non-zero	Zero	Non-zero	Zero
Non-zero	87%	13%	92%	8%	93%	7%	90%	10%
Zero	17%	83%	20%	80%	22%	78%	31%	69%

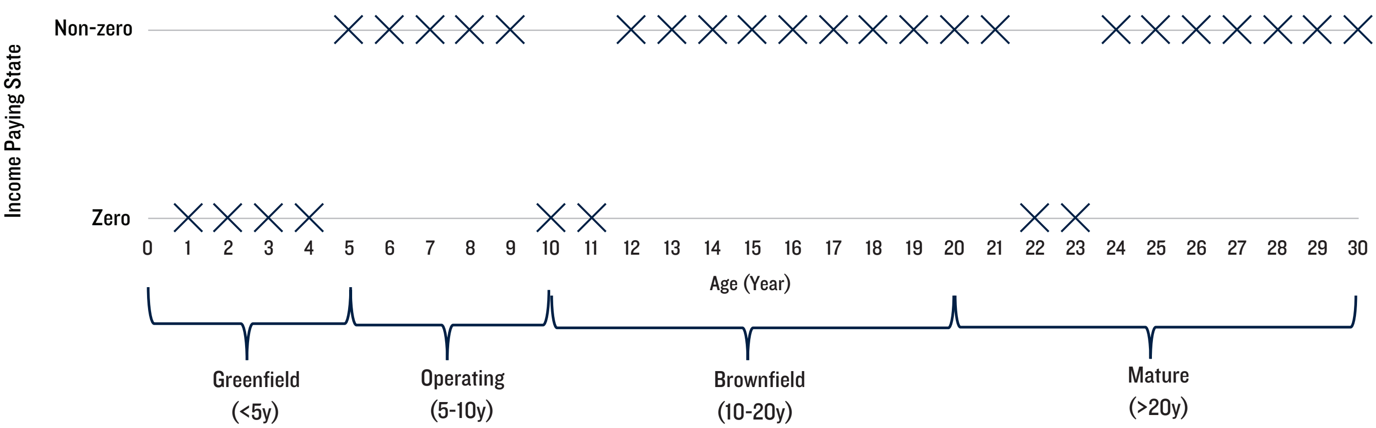
Note: Underlying annual income returns are from 690 assets in EDHEC*infra* database from Q1 2000 to Q2 2021. Source: EDHEC*infra*, PGIM IAS. As of Q2 2021. Provided for illustrative purposes only.

For each market simulation path, at each period of evaluation the model chooses whether each infrastructure asset will generate an income return this year based on the probabilities from this first transition matrix set.

This set of transition matrices matches investor intuition. The probability of an asset switching from a Zero to a Non-zero income paying state increases from 17% to 31% as the asset ages from *Greenfield* to *Mature*. In addition, an income-paying asset is more likely to remain income-paying once it ages beyond *Greenfield* (*i.e.,* 5y). However, there is always a chance that an asset that paid income last year may not generate income this year, thus contributing to an asset's and, hence, a portfolio's cash flow variability.

Figure 18 illustrates a hypothetical sequence of Zero/Non-zero income return states over the lifespan of an infrastructure asset – Step 1. As shown, this asset happens to begin its life in a zero income return state. By year 5 it begins to persistently generate an income return. Nevertheless, as the asset ages it may occasionally fail to produce income in a year, and this Zero income state could persist for a year or two (or more).

Figure 18: Income Return States for a Hypothetical Infrastructure Asset



Note: Probability of Non-zero income state at the first period is set empirically at 33%. Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

Step 2: If an infrastructure asset is paying an income return in a year, we then need to determine "how much income return?" To do so, we first examine historical sector income returns and identify quartiles. We then use the **Income Return Quartile Transition Matrix** to determine the asset's income return quartile for that year.[29] Figure 19 shows an asset's annual income return quartile transition matrix, by sector. The values in the cells indicate the probabilities of transitioning from a preceding year's income return quartile (indicated by the row) to a quartile (ranging from Q1 (bottom) to Q4 (top)) for the current year (column). For example, if a *Transport* asset generated top quartile (Q4) income return in the preceding year, there is a 61% probability it will produce a top quartile income return again this year; a 24% chance of switching to Q3; an 8% probability of switching to Q2; and a 6% chance that it generates bottom Q1 income return this year (see red rectangle).

For each simulated market path, at each period of evaluation the model selects an income return quartile for each infrastructure asset based on the probabilities from this second transition matrix set.

29 The income return quartiles are determined from sector-specific income return distributions (positive skewed) that are fit as beta distributions (continuous probability distributions defined on the interval [0, 1] controlled by two shape parameters, alpha (α) and beta (β)), calibrated by EDHEC*infra*. Appendix A8 provides the beta distribution parameters. The sector-specific income return distribution, unconditional on a specific asset, reflects both cross-sectional income return volatility (volatility of income return at each period) and time-series income return volatility (volatility of the expected income return over time).

Figure 19 indicates that an asset's income return this year is most likely to be in the same income return quartile as the preceding year (see the shaded diagonal values) – indicating some persistence in the level of income return for an infrastructure asset. This empirical pattern matches investor intuition.

Figure 19: Annual Income Return Quartile (in a Non-Zero State) Transition Matrix, by Sector

Power Generation x-Renewables				
	Q1	Q2	Q3	Q4
Q1 – Bottom	63%	19%	11%	6%
Q2	18%	54%	19%	8%
Q3	9%	17%	52%	22%
Q4 – Top	8%	10%	19%	63%

Social Infrastructure				
	Q1	Q2	Q3	Q4
Q1	60%	17%	16%	7%
Q2	20%	49%	22%	10%
Q3	10%	28%	41%	21%
Q4	7%	13%	22%	58%

Transport				
	Q1	Q2	Q3	Q4
Q1	66%	17%	7%	10%
Q2	16%	54%	21%	9%
Q3	9%	22%	49%	20%
Q4	6%	8%	24%	61%

Environmental Services				
	Q1	Q2	Q3	Q4
Q1	63%	16%	11%	11%
Q2	14%	59%	16%	12%
Q3	10%	19%	50%	21%
Q4	4%	11%	27%	58%

Renewable Power				
	Q1	Q2	Q3	Q4
Q1	69%	16%	6%	9%
Q2	14%	51%	23%	13%
Q3	8%	20%	49%	23%
Q4	5%	16%	27%	52%

Network Utilities				
	Q1	Q2	Q3	Q4
Q1	63%	17%	9%	11%
Q2	19%	41%	26%	14%
Q3	10%	28%	40%	22%
Q4	11%	13%	25%	51%

Energy and Water Resources				
	Q1	Q2	Q3	Q4
Q1	69%	17%	6%	8%
Q2	19%	59%	15%	7%
Q3	5%	17%	59%	19%
Q4	10%	6%	17%	68%

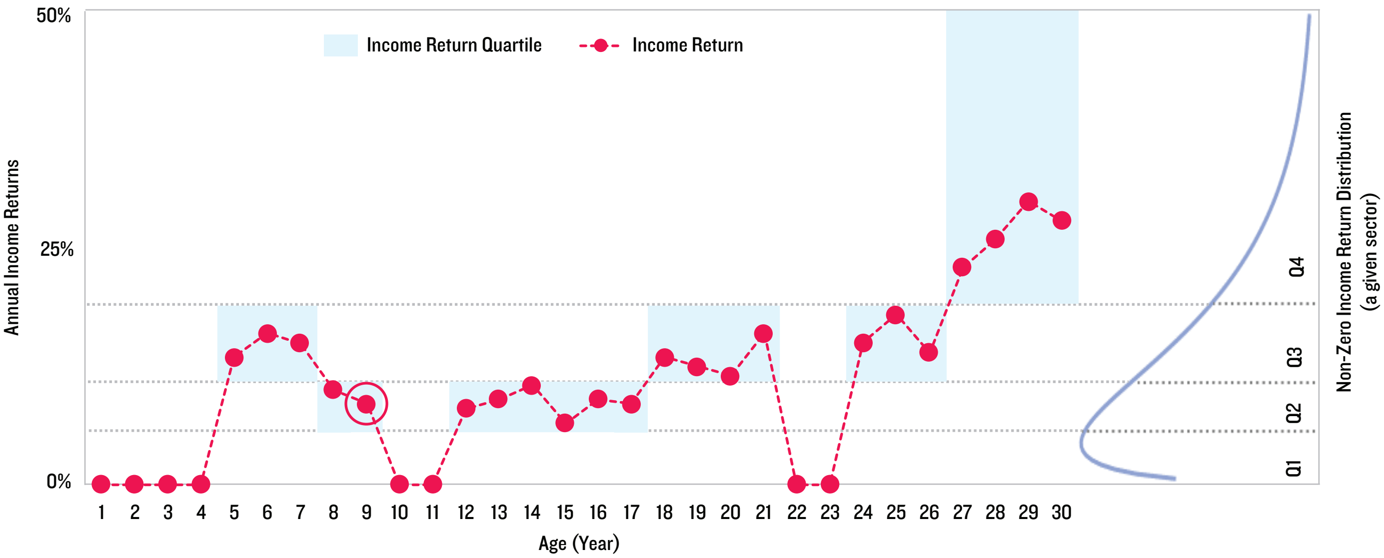
Data Infrastructure				
	Q1	Q2	Q3	Q4
Q1	67%	11%	0%	22%
Q2	30%	40%	20%	10%
Q3	8%	23%	46%	23%
Q4	0%	30%	20%	50%

Note: Underlying annual income returns are from 690 assets in EDHEC*infra* database from Q1 2000 to Q2 2021. Source: EDHEC*infra*, PGIM IAS. As of Q2 2021. Provided for illustrative purposes only.

Step 3: If an infrastructure asset is paying an income return in a year (Step 1), and we know the quartile of income return for that year (Step 2), we then randomly sample a *specific* income return from the Step 2 selected income return quartile. For example, see the red circle for year 8 in Figure 20. For this simulated market path, the asset in year 8 has a positive income return drawn from Q2. The right side of the figure shows a right-skewed income return distribution, for a given sector, partitioned into its four quartiles. Each quartile has a range of income returns (colored bars). For this example, the value of the income return in year 8 happens to be at the upper end of Q2 for the asset's sector.

For a given simulated market path, this process is repeated for this and all years forward, producing a series of red dots connected by the dashed line in Figure 20. Although the income return in a given year can switch quartiles (*e.g.*, as occurs in this example between years 7 and 8), there is some persistence of staying in a quartile as suggested by the transition matrices. Note that for some years income returns are zero.

Figure 20: Hypothetical Asset Lifespan Income Return (and Quartile) Sequence



Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

By aggregating the lifespan income return profiles for a portfolio of infrastructure assets of (possibly) different sectors and ages, we can construct and estimate the income return profile of any infrastructure asset portfolio based on:

- The number of assets in the portfolio;
- The age groups of the infrastructure assets; and
- The sector composition of the infrastructure portfolio.

Income Return Volatility of an Infrastructure Asset Portfolio

When investing in an infrastructure asset, the CIO knows that there will be some volatility in the asset's income return over its lifespan. However, the CIO faces additional uncertainty: Which particular asset might the CIO select from a pool of similar assets? As shown earlier, assets from the same sector are far from identical and some may perform *persistently* well or poorly. *Ex ante,* the CIO does not know which asset they will select, and this uncertainty should be captured when measuring income return risk. Our **income return volatility measure** combines both *time-series (or lifespan) volatility* (the volatility of the expected income returns of an asset over time) and *cross-sectional volatility* (the volatility of the income returns across a population of similar assets).

Suppose a CIO looks to invest in a *greenfield* (*e.g.,* 2y old) infrastructure asset in the *Renewable Power* sector. Following the income return modeling methodology above, Figure 21 shows three hypothetical sample paths of quarterly income returns (%) over a 10y horizon – representing three possible paths for a prospective *greenfield* asset selected from the *Renewable Power* sector. Each income return path represents a possible lifespan path for the infrastructure asset. *Which* path will the CIO experience? No one knows yet, and this uncertainty of idiosyncratic income return of a prospective infrastructure asset is captured by **cross-sectional income return volatility**.

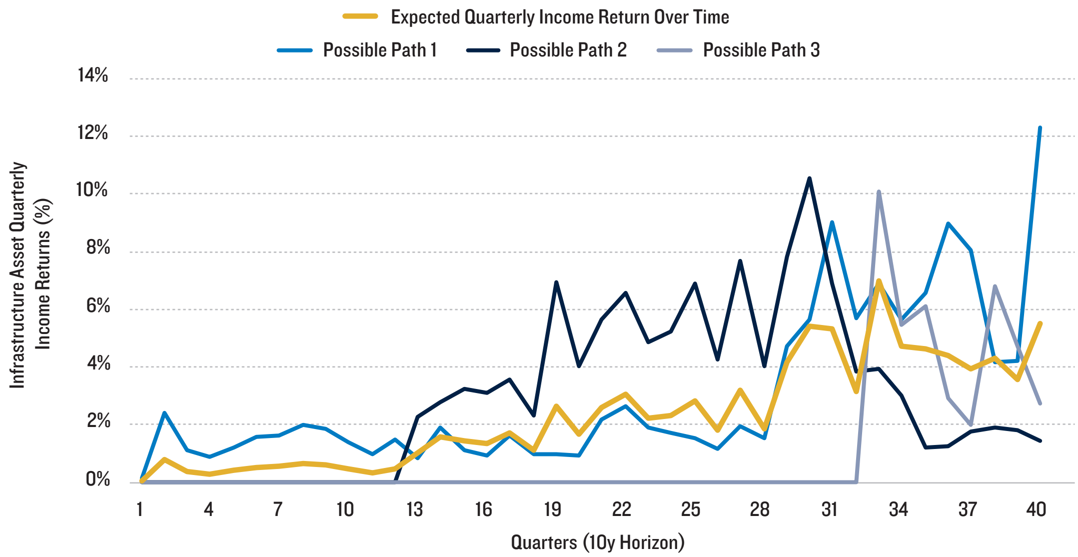
In addition, we can generate the expected quarterly income return, over time, by calculating each period's average quarterly income return across the three possible paths for the prospective renewable asset.[30] The volatility of this expected income return over time is measured by **times-series income return volatility**.[31]

30 For *greenfield investments* the expected quarterly income return could gradually increase over time reflecting the lifespan behavior of the asset's income returns (as Figure 21 red line indicates).

31 As sample size becomes large the times-series income return volatility measure will be more reliable.

Figure 21: Three Quarterly Income Returns Path for the Prospective Asset

(2y-old *Renewable Power* Infrastructure Asset)



Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

Assuming 5,000 simulated market paths, we introduce the following measures to evaluate the level and volatility of income return over 10y for a portfolio of infrastructure asset(s). Since zero income returns could occur during the lifespan of an infrastructure asset, such occurrences are included in all calculations.

1. Expected quarterly income returns – calculated as the average of 40 average quarterly income returns

$$\text{Expected quarterly income return} = E(E(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q}) \tag{1}$$

2. Time-series quarterly income return volatility ($\sigma_{time-series}$) – calculated as the volatility of the 40 average quarterly income returns

$$\sigma_{time-series} = \sigma(E(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q}) \tag{2}$$

3. Cross-sectional quarterly income return volatility – calculated as the average of the 40 cross-sectional volatilities of quarterly income returns

$$\sigma_{cross-sectional} = E(\sigma(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q}) \tag{3}$$

4. In addition to the measures above, the Expected Coefficient of Variation (CV) is defined as:[32]

$$Expected\ CV = E(\frac{\sigma(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q}}{E(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q}}) \tag{4}$$

5. Finally, 2 and 3 can be combined to represent the **total income return volatility** of an infrastructure portfolio over 10y:[33]

$$\sigma_{total} = \sqrt{\widehat{Var_{cross-sectional}} + Var_{time-series}} \tag{5}$$

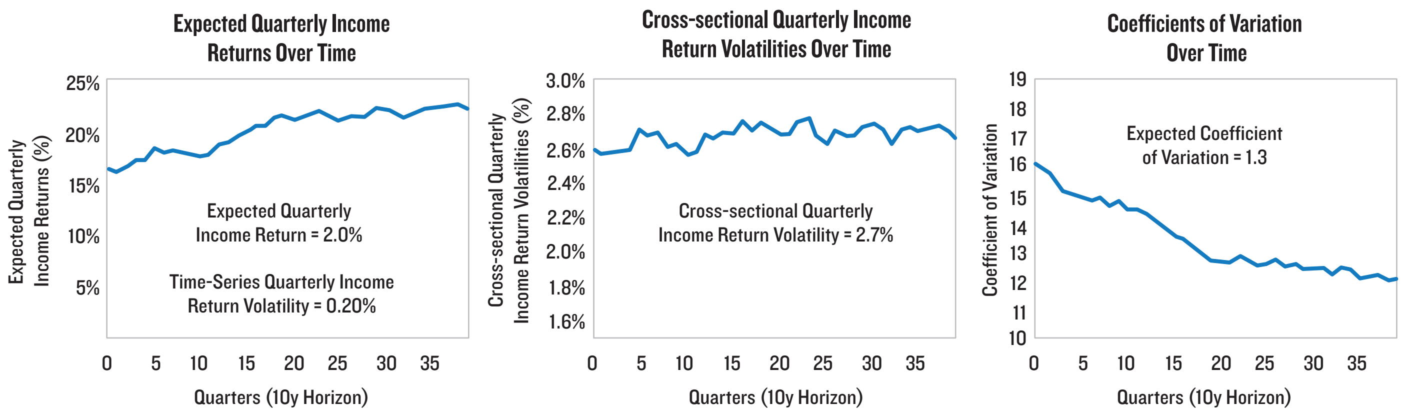
Figure 22 illustrates these income return measures using a single 2y-old *Renewable Power* infrastructure asset as an example. The expected quarterly income return gradually rises over time – typical for a *greenfield* infrastructure asset – with an expected quarterly income return of 2.0% with a 0.2% time-series volatility. However, the cross-sectional quarterly income return volatility is 2.7% which is almost 10× the time-series volatility and is relatively large compared to the expected income return (2.0%). As the asset matures the coefficient of variation (CV) declines over time (driven by increasing expected income returns) with an expected value of 1.3.

32 The coefficient of variation (CV) is the ratio of the standard deviation to the mean and shows the extent of variability scaled by the mean of the population. CV allows for comparison across data series with different means.

33 Note: $\widehat{Var_{cross-sectional}} = E(Var(quarterly\ income\ return_{sim = 1\ to\ 5000})_{t= 1\ to\ 40\ q})$

Figure 22: Quarterly Income Returns: Level and Variability

(2y-old *Renewable Power* Infrastructure Asset)



Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

With our measures for expected income return and volatility, we can compare the expected income return level and volatility both for a single asset and for a group of infrastructure assets.[34] In addition, we can quantify the relative **diversification benefits** of either increasing the number of assets in an infrastructure portfolio or expanding the portfolio's sector exposures. Which strategy generates the larger incremental diversification benefit?

We compare four portfolios, Portfolios A through D (Figure 23). Portfolio A and B each contain one *Renewable Power* asset but differ by the age of the asset – a *greenfield* asset for Portfolio A and a *brownfield* asset for Portfolio B. Portfolio C contains 10 *brownfield Renewable Power* assets while Portfolio D contains 10 *brownfield* assets across multiple sectors.[35] Figure 24 compares the income return level and volatility for each portfolio.[36]

Figure 23: Diversification Potential – Number of Assets or Sectors?

Four Infrastructure Portfolios

	Portfolio A	Portfolio B	Portfolio C	Portfolio D
Number of Assets	1	1	10	10
Age of Assets	2y (Greenfield)	16y (Brownfield)	16y (Brownfield)	16y (Brownfield)
Sector Exposure	Renewable Power	Renewable Power	Renewable Power	Diversified Sector Exposure

Note: All *brownfield* assets are assumed to be 16y old at time of evaluation for fair comparison. Source: PGIM IAS. Provided for illustrative purposes only.

Comparing Portfolios A and B (dark blue *vs.* light blue dashed lines), both single-asset portfolios in the same sector, highlights the income return difference between *greenfield* and *brownfield* assets. The expected quarterly income returns of Portfolio A (*greenfield*) keep rising and almost catches up to the expected quarterly income returns of Portfolio B by year 10 (Figure 24). Portfolio A's CV gradually declines, approaching Portfolio B's. The expected 10y CV of Portfolio A is higher than Portfolio B's (1.34 *vs.* 1.14). Finally, Portfolio A's time-series quarterly income return volatility is higher than Portfolio B's (0.20% *vs.* 0.08%), reflecting the higher income return uncertainty during an asset's *greenfield* stage than during its *brownfield* stage.

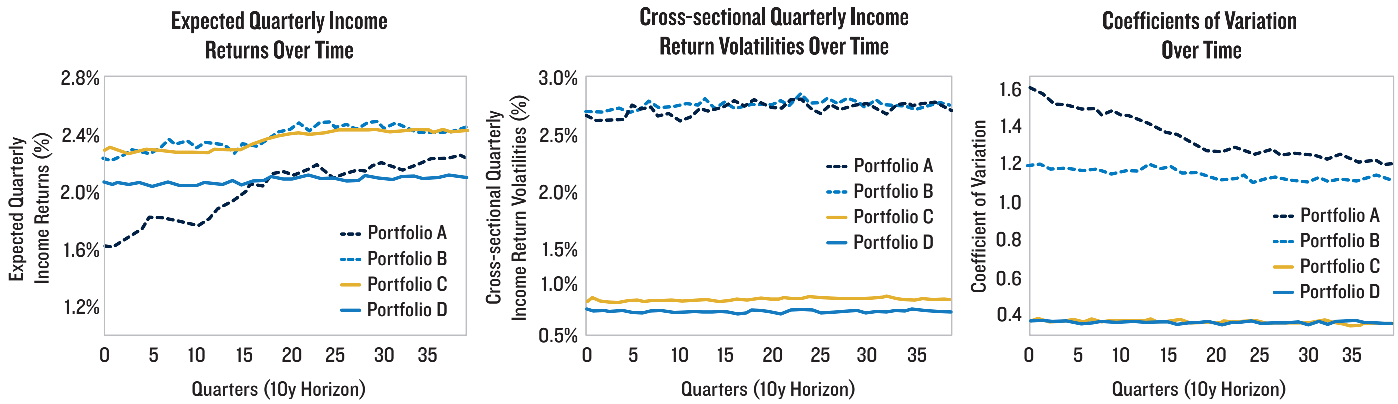
Comparing Portfolios B and C (light blue dashed line *vs.* gold solid line), containing one *vs.* ten *Renewable Power brownfield* assets, respectively, reveals diversification benefits associated with increasing the number of assets in the infrastructure portfolio. Figure 24 shows no significant difference in expected quarterly income returns for the two portfolios with essentially identical time-series volatility (0.07% *vs.* 0.08%). This is not surprising as both portfolios contain the same type of asset, so expected returns and volatility over time will be similar. However, the cross-sectional quarterly income volatility (2.71% *vs.* 0.85%) and CV (1.14 *vs.* 0.36) of Portfolio C with 10 assets are much lower than those for the single-asset Portfolio B. The large reduction in income return volatility associated with asset selection risk is significantly mitigated with a larger number of assets in the portfolio.

34 The quarterly income returns of an infrastructure portfolio are calculated based on individual asset's quarterly income returns weighted by their respective quarterly valuation. See equation (10) in **Section V**.

35 Portfolio D's sector composition: 2 *Transport*, 2 *Power Generation x-Renewables*, 2 *Social Infrastructure*, 2 *Renewable Power* and 2 *Network Utilities*.

36 We selected *Renewable Power* as the sector for this analysis. However, we examined all other sectors for sector concentration analysis and the findings remained consistent.

Figure 24: A Comparison of Quarterly Income Returns; Expected Level and Volatility Measures
(Portfolios A, B, C and D)

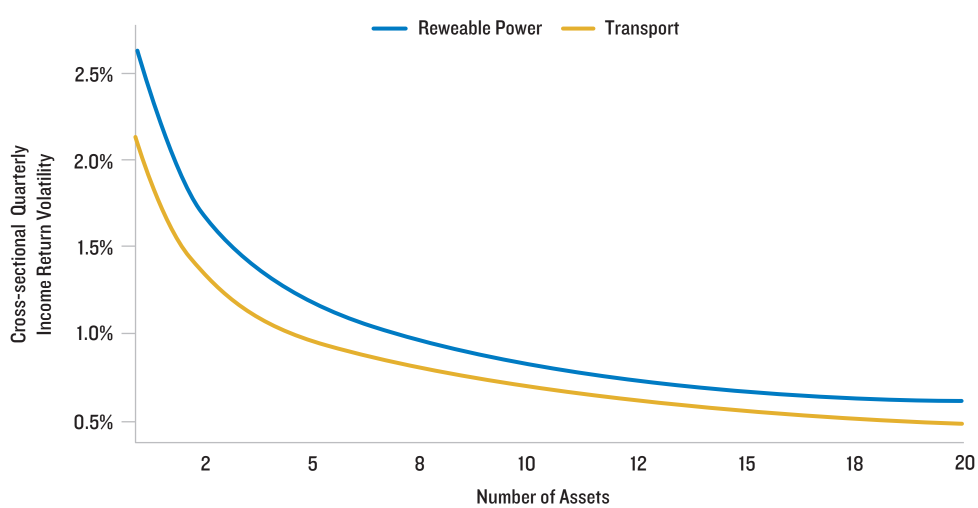


	Portfolio A	Portfolio B	Portfolio C	Portfolio D
Expected Quarterly Income Return	2.01%	2.37%	2.35%	2.08%
σ *time-series*	0.20%	0.08%	0.07%	0.02%
σ *cross-sectional*	2.67%	2.71%	0.85%	0.74%
σ *total*	2.68%	2.71%	0.86%	0.74%
Expected Coefficient of Variation (CV)	1.34	1.14	0.36	0.36

Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

Inquiring minds might like to know how many infrastructure assets are needed to significantly reduce idiosyncratic volatility. Figure 25 shows the speed of reduction in idiosyncratic risk (*i.e.,* $\sigma_{\text{cross-sectional}}$) as the number of assets increases in a *Renewable Power and Transport* portfolio (*i.e.,* from 1 asset to 20 assets). $\sigma_{\text{cross-sectional}}$ starts to level off as the number of assets reaches 7, and the marginal reduction in $\sigma_{\text{cross-sectional}}$ with one additional asset becomes quite small once the number of assets approaches 10.[37]

Figure 25: Cross-sectional Quarterly Income Return Volatility for Different Number of Assets in Portfolio
(Renewable Power and Transport Sectors)



Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

37 In reality, it might be difficult for an investor to simultaneously invest in seven or more individual infrastructure assets in the same sector to achieve effective diversification of idiosyncratic risk.

Single-sector Portfolio C and multi-sector Portfolio D (gold line *vs.* grey line in Figure 24) both contain the same number of *brownfield* assets. Perhaps surprisingly, Portfolio D, with its lower time series volatility (recall Figure 13), has only a modestly lower cross-sectional income return volatility compared to Portfolio C (0.85% *vs.* 0.74%) despite its broad sector diversification. Figure 26 suggests why: total quarterly income return volatility and the expected CV for portfolios of 10 sector-specific assets are *comparable, irrespective of the sector*. Furthermore, total quarterly income return volatility and the expected CV for the 10-asset sector-specific portfolios are comparable to the 10-asset sector-diversified Portfolio D.

The takeaway for a CIO investing in infrastructure assets is that idiosyncratic risk is important, much greater than time series risk, but can be mitigated by holding more assets. However, to reduce idiosyncratic risk, adding assets from the same sector may be as efficacious as adding the same number of assets from different sectors. This finding may allow the CIO to economize on portfolio management resources – concentrate on just a few sectors, and diversify by holding many assets. Figures 24 and 26 suggest that **so long as the portfolio size increases to alleviate idiosyncratic income return risk, further reduction in cross-sectional income return volatility from sector diversification appears limited.**

Figure 26: Quarterly Income Returns Level and Volatility Measures
(Sector-specific Portfolios of 10 Brownfield Assets, by Sector)

10 Brownfield (16y) Assets by Sector	Transport	Power Generation x-Renewables	Social Infrastructure	Renewable Power	Network Utilities
Expected Quarterly Income Return	1.80%	3.09%	1.59%	2.35%	1.78%
$\sigma_{\textit{time-series}}$	0.05%	0.08%	0.04%	0.07%	0.05%
$\sigma_{\textit{cross-sectional}}$	0.69%	1.00%	0.53%	0.85%	0.62%
$\sigma_{\textit{total}}$	0.69%	1.01%	0.53%	0.86%	0.62%
Expected Coefficient of Variation (CV)	0.38	0.32	0.33	0.36	0.35

Note: The portfolio of 10 *brownfield Renewable Power* assets is the same as Portfolio C in Figure 24. Only five sectors are shown. Source: EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

Modeling Income Returns for Prospective & Existing Investments

CIOs face both cross-sectional and time-series income return volatility when planning to invest in infrastructure assets. The analysis presented thus far assumes such prospective infrastructure asset investments. However, once the investment is made, the CIO experiences only the time-series income return volatility associated with the asset's unknown future income returns.

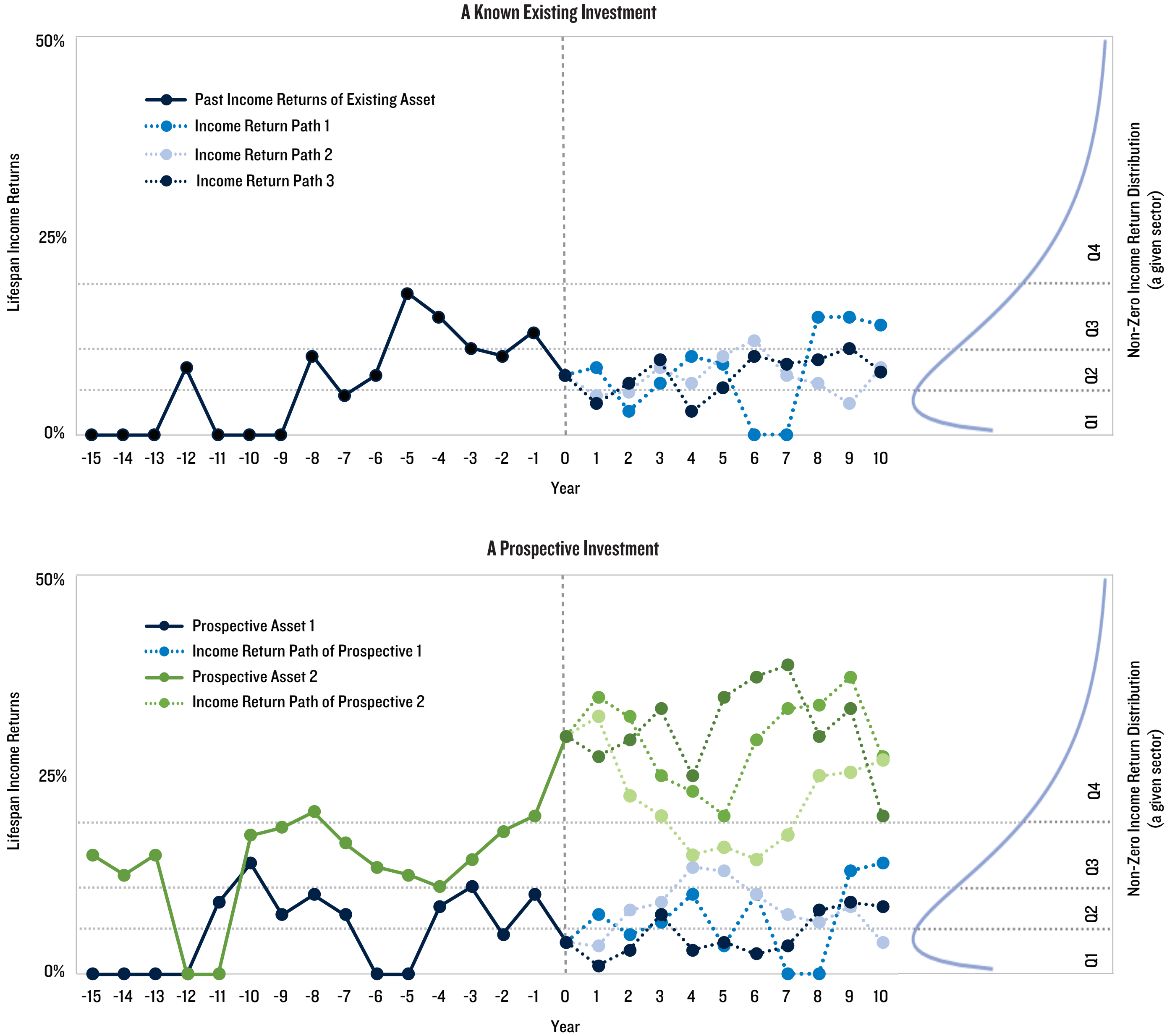
Institutional portfolios generally contain both a mix of existing infrastructure assets as well as a plan to invest in additional assets (stemming from a portfolio NAV% target or reinvestment strategy). Figure 27 illustrates how income return volatility can differ between existing and prospective asset investments, suggesting a differentiated approach to modeling income returns. At the time of portfolio evaluation (say, today or "year 0"), the past income returns of a hypothetical *existing* asset is known and fixed, although the investor still faces uncertainty in terms of future income return (top panel). The income return in subsequent periods (year 1) will follow the Markov process introduced above – which displays significant persistence – given the known starting point at year 0. This holds across all market simulation paths.

For *prospective* asset investments at year 0 there is uncertainty associated with which asset will be selected. Different assets (asset 1 and 2 in Figure 27, bottom panel) may have experienced different income return paths prior to year 0 or they may be entirely new investments with no track record. Consequently, the income return for year 1, which depends heavily on the income return for year 0, will depend on which asset the CIO selects.

Figure 28 compares the distribution of annual income returns of an existing and prospective infrastructure asset investment over 5y (across the 5,000 market paths) beginning in year 0. For the existing investment, we select an infrastructure asset (16y-old *Renewable Power* asset with quartile Q3 income return at year 0) and fix this as the asset's starting point for all market simulation paths. For the prospective investment, we generate a unique historical income return path for each market simulation path to represent the CIO's asset-selection uncertainty. For a fair comparison, we assume the sector and the age of the prospective investment is the same as the existing investment (16y-old *Renewable Power*).

Figure 27: Comparing Income Return Volatilities – Existing & Prospective Investments

An Illustration



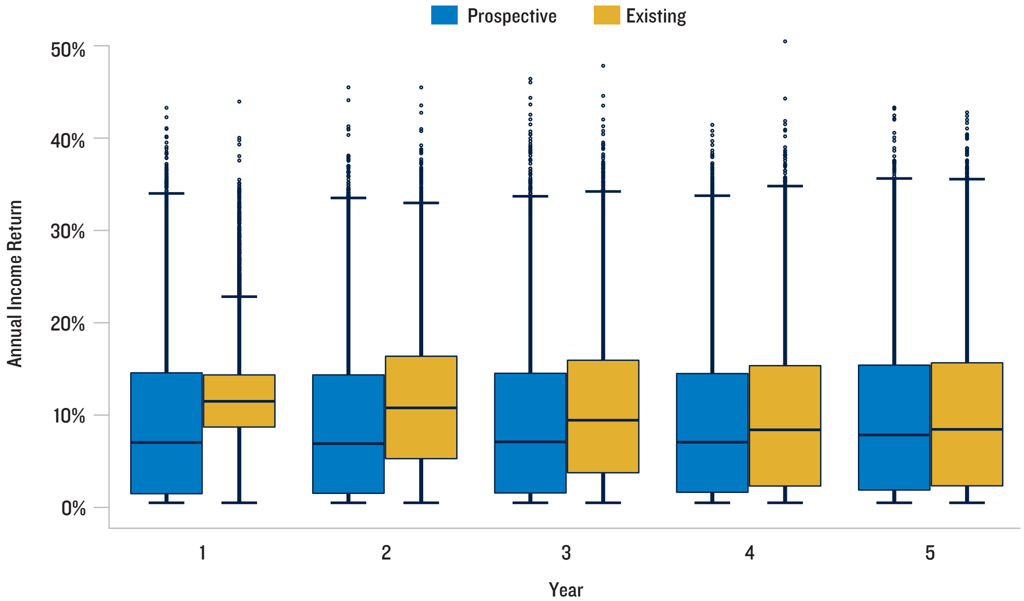
Note: The income paths of existing and prospective investment are all hypothetical. Source: PGIM IAS. Provided for illustrative purposes only.

Figure 28 shows that the existing asset investment starts with a narrower dispersion of possible annual income returns (including zero income returns) than that of the prospective investment due to the absence of the former's investment selection uncertainty.[38] However, the distribution of the existing asset's possible income returns becomes wider due to the income return transition matrices, and by year 5 is almost the same as that of the year 0 prospective asset investment in year 5. Although there is persistence in each income return path (as shown in Figure 27, top panel), as the future unfolds the potential income return paths will exhibit wider income ranges, causing the median income returns of an existing and a prospective investment to converge. Nevertheless, our income return modeling approach reflects that a CIO faces more cash flow uncertainty from prospective investments than from existing investments, at least initially.

38 That the income return dispersion of the existing investment becomes wider over time and the median income return converges to that of a prospective infrastructure investment hold regardless of which existing asset is selected.

Figure 28: Annual Income Return Volatility Comparison

An Illustration



Source: PGIM IAS. For illustrative purposes only.

IV. Asset Allocation with Unlisted Infrastructure Investments

We employ an asset allocation framework (OASIS™) to evaluate the performance-liquidity tradeoff of a hypothetical foundation portfolio with different infrastructure allocations

- We illustrate the performance-liquidity tradeoff impact of allocating to infrastructure investments
- We find that adding infrastructure investments, especially infrastructure assets, could *improve* portfolio liquidity, driven by infrastructure assets' reduced cash flow variability
- The framework is flexible and highly customizable to incorporate a CIO's unique strategic asset allocation, private asset commitment strategies and infrastructure allocation, *etc.*

CIOs allocating to illiquid private assets face several challenges, including:

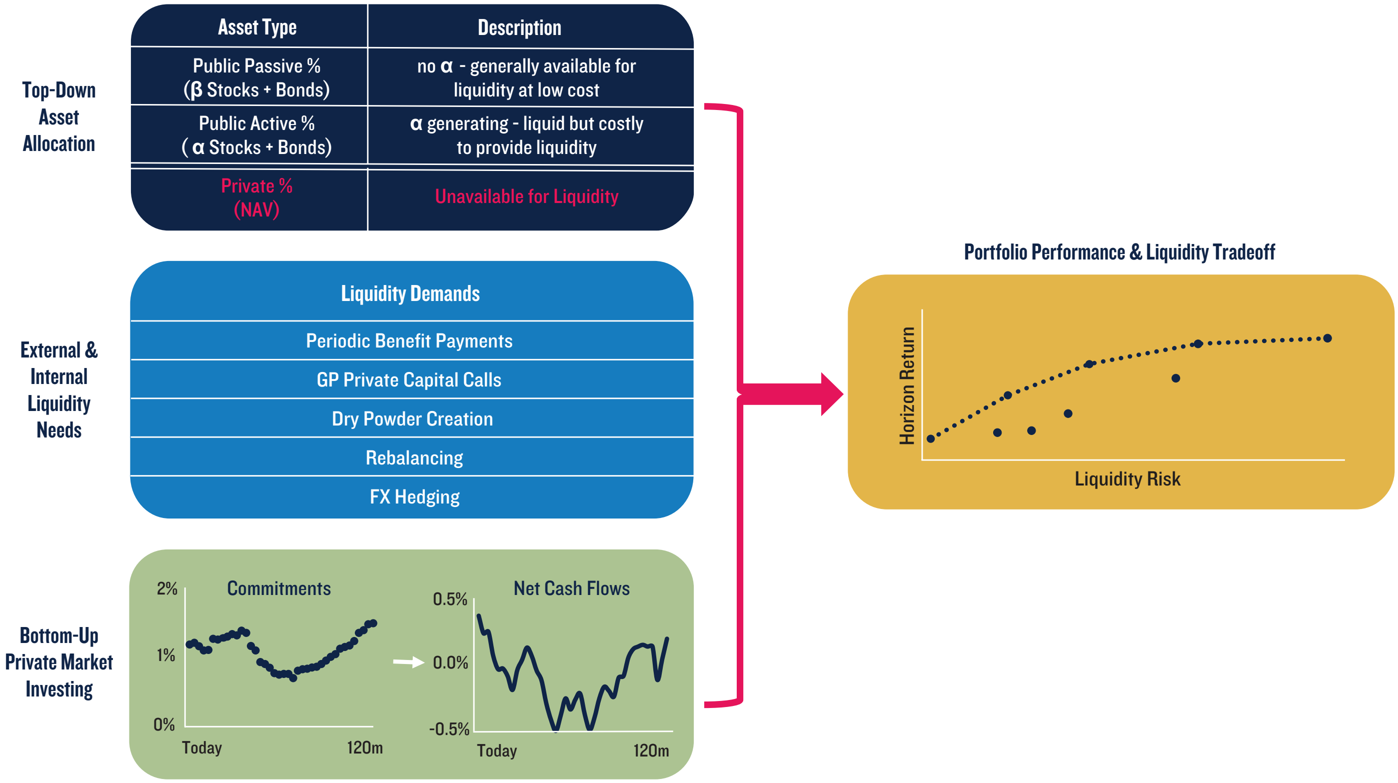
- How to quantitatively evaluate the implications for portfolio liquidity of various allocations to illiquid assets?
- How to manage illiquid asset exposures and the uncertainty in timing and magnitude of their cash flows? and
- How to allocate to illiquid assets to maximize expected portfolio performance while keeping liquidity risk within the CIO's tolerance level?

OASIS can help CIOs analyze how their private investing activity affects their portfolio's ability to respond to liquidity demands. Figure 29 presents the three components of OASIS.[39] The first generates simulated public returns based on the CIO's capital market assumptions and asset allocation. The second component produces private asset cash flows and valuations based on public returns and the CIO's fund-selection skill, commitment strategy and views on private assets. The interaction of returns and cash flows with the plan's liquidity demands (the third component) produces the portfolio's tradeoff between liquidity risk and expected performance.

To study how various allocations to infrastructure investments interact with other private assets (*e.g.,* private equity) and impact portfolio performance and liquidity risk, we incorporate our infrastructure cash flow modeling into OASIS. We model cash flows of infrastructure funds and assets *separately* (Figure 2). Fund cash flows take the form of GP capital calls and distributions while asset cash flows take the form of dividend income.

39 See J. Shen, *et al.*, "Harnessing the Potential of Private Assets: A Framework for Institutional Portfolio Construction," 2021, PGIM IAS, and J. Shen, *et al.*, "Asset Allocation and Private Market Investing," *Journal of Portfolio Management*, 2021, for details on OASIS and private asset cash flow modeling.

Figure 29: OASIS Structure



Source: PGIM IAS. Provided for illustrative purposes only.

Modeling Cash Flows of Infrastructure Funds

OASIS models cash flows for infrastructure funds using the TA cash flow model, similar to its modeling of PE fund cash flows. For *future* vintage-level fund investments the TA *Rate of Contribution* and *Bow* parameters are estimated from historical vintage-level average values for infrastructure funds while the *Growth (G)* parameter is estimated based on simulated public market returns.[40] Therefore, fund cash flow estimates will reflect, to some extent, ongoing public market conditions. We do not differentiate sector exposures for modeling fund cash flows as most funds are diversified (or generalist) sector funds.[41]

Modeling Cash Flows of Infrastructure Assets

We derive an infrastructure asset's quarterly dividend income (*i.e.,* cash flows – $) from the asset's quarterly income return (%), as modeled in **Section IV**, using the asset's preceding period's valuation.

$$Quarterly\ Dividend\ Income\ (Cash\ Flow)_{asset,t} \ = \ Quarterly\ Income\ Return_{asset,t} \times Infra\ Asset\ Valuation_{asset,t-1} \tag{6}$$

$$Infra\ Asset\ Valuation_{asset,t} \ = \ (1 + \ Quarterly\ Price\ Return_{asset,t}) \times Infra\ Asset\ Valuation_{asset,t-1} \tag{7}$$

Accordingly, the cash flow for a portfolio of infrastructure assets is as follows:

$$Quarterly\ Dividend\ Income\ (Cash\ Flow)_{portfolio,t} \ = \sum Quarterly\ Dividend\ Income\ (Cash\ Flow)_{asset,t} \tag{8}$$

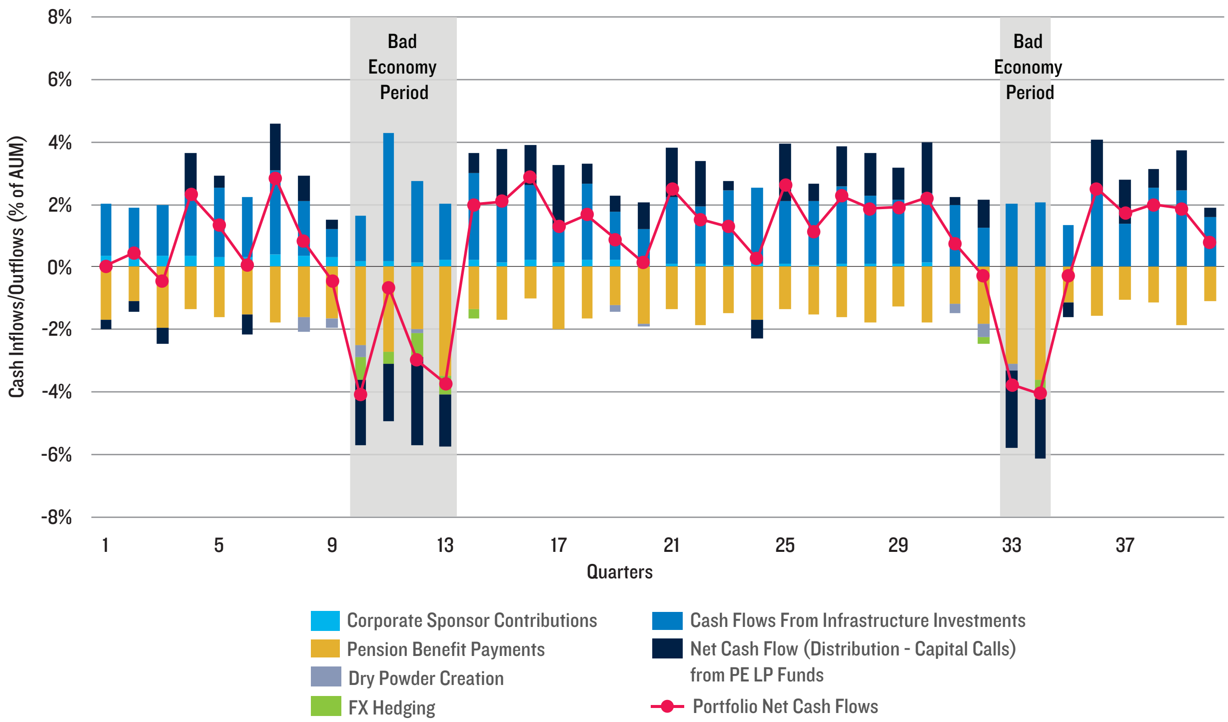
$$Infra\ Asset\ Valuation_{portfolio,t} = \sum Infra\ Asset\ Valuation_{asset,t} \tag{9}$$

$$Quarterly\ Income\ Return_{portfolio,t} = \frac{DividendIncome(CashFlow)_{portfolio,t}}{Infra\ Asset\ Valuation_{portfolio,t-1}} \tag{10}$$

40 Appendix A6 compares the calibrated TA parameters for global infrastructure and US buyout funds of historical vintages. See J. Shen and M. Teng, 2021 for details of private equity valuation methodology.

41 For example, as of Q1 2022, there are 1,646 global diversified (or generalist) sector funds out of 2,481 buyout funds in Burgiss representing $2.6t out of $3.3t market capitalization.

Figure 30: Portfolio Cash Inflows & Outflows, by Source



Note: Figure 30 illustrates cash flows of a hypothetical corporate DB plan. Source: PGIM IAS. Provided for illustrative purposes only.

During each period (*i.e.,* quarter) along a market path, OASIS tracks infrastructure and other private asset cash in(out)flows and the portfolio's periodic cash requirements.[42] Figure 30 illustrates the time series of cash in(out)flows, by category, and the aggregated portfolio net cash flow.

Portfolio periodic net cash flows can become very negative during bad economic environments, producing liquidity stress. In OASIS, liquidity measurement and cash flow management can be formally integrated to examine if a portfolio can meet its liquidity demands across different market environments while keeping the risk of an unnerving or debilitating liquidity event at a level acceptable to the CIO.

Portfolio Implications of Allocating to Infrastructure Investments

We consider a hypothetical foundation portfolio with an annual spending obligation of 5% of assets and a set of capital market assumptions. We further assume the foundation needs to rebalance quarterly across its cash, public fixed income and growth asset portfolios subject to tolerance ranges.[43]

Figure 31 presents three portfolio asset allocations, all with the same public asset allocations. However, in terms of illiquid private assets, PortA has only PE fund investments. PortB replaces 10 percentage points of PortA's PE allocation with a portfolio of infrastructure *assets* consisting of a mix of ten *operating* and *brownfield* assets with diversified sector exposure.[44] Finally, PortC replaces 10pp of the PE allocation in PortA with an allocation to infrastructure *funds*. Note that fund returns are net of fees whereas public asset and infrastructure asset returns are gross of fees. The commitment pacing strategies for private funds (PE or infrastructure) in all three portfolios are designed such that their respective initial allocation is maintained over time, on average.

OASIS compares portfolio horizon performance, rebalancing failures and liquidity risk across the three portfolios (Figure 32). Although there are many ways a CIO might define liquidity risk, we assume the foundation's CIO becomes concerned if they must sell 3.5pp of its liquid assets. Replacing 10pp of PE fund allocation with 10% infrastructure assets (PortB) *improves* portfolio liquidity. The probability of a rebalancing failure falls from 9.3% (PortA) to 1.8% (PortB) and the probability of needing to sell 3.5pp of liquid assets for liquidity needs falls from 8.5% to 1.2%.

42 For a corporate defined benefit plan these cash flows can include (but are not limited to) pension benefit payments, corporate sponsor contributions, margin calls on futures positions, calendar rebalancing needs, tactical dry power creation by selling liquid assets, *etc.*

43 For this example, Appendix A9 contains OASIS assumptions including public and private assets CMAs, rebalancing tolerances, and PE and infrastructure fund commitment pacing strategies.

44 Appendix A9 includes details of the infrastructure asset portfolio in terms of the number of assets, ages, sectors, and portfolio weights at the beginning of the 10y horizon. These assumptions can be customized to match an investor's infrastructure asset exposures.

Figure 31: Three Alternative Portfolio Asset Allocations

	Asset Allocations	PortA	PortB	PortC
	Cash	5%	5%	5%
	Public Fixed Income Portfolio	25%	25%	25%
Growth Assets	Passive Public Equity	15%	15%	15%
Growth Assets	Active Public Equity	25%	25%	25%
Growth Assets	Private Equity Funds	30%	20%	20%
Growth Assets	Direct Infra Assets Investments	0%	10%	0%
Growth Assets	Infrastructure Funds	0%	0%	10%

Source: PGIM IAS. Provided for illustrative purposes only.

The improvement in portfolio liquidity risk arises from the lower total quarterly income return volatility of infrastructure assets compared to that of PE (0.9% *vs.* 2.7%), despite PE's slightly higher expected quarterly income return (2.5% *vs.* 2.3%). The income returns of infrastructure assets and, in turn, their cash flows are relatively stable as assets mature and have low sensitivity to the contemporaneous public market environment. In contrast, cash flows from funds are more volatile and uncertain as investors could experience large capital calls and/or small distributions when the portfolio most needs liquidity. In addition, the cash flow experience of private asset fund investments depends on the CIO's commitment pacing strategy.

Replacing 10pp of PE funds with 10pp infrastructure funds (PortC) also *improves* portfolio liquidity, although only moderately. The probability of rebalancing failures falls only from 9.3% (PortA) to 8.0% (PortC) and the probability of being forced to sell 3.5pp of liquid assets for liquidity needs falls from 8.5% to 6.0%. Although infrastructure fund quarterly total income return volatility is lower than that of PE (1.9% *vs.* 2.7%), the expected quarterly income return is also lower (1.7% *vs.* 2.5%). In other words, the cash flow characteristics of infrastructure funds, in terms of CV, do not appear to differ much from PE funds.

The improvement in portfolio liquidity arises rather from a diversification benefit provided by infrastructure funds to the overall fund allocation. On one hand, cash flows of infrastructure and PE funds are modeled using specifically calibrated TA parameters, including the horizon growth rates (G) that respond to the long-term public market environment.[45] In other words, net cash flows are diversified from the imperfectly correlated cash flows between infrastructure and PE funds. On the other hand, we assume the number of PE funds invested in PortC is the same as in PortA. With the inclusion of infrastructure funds, the number of total funds invested increases, contributing further to cash flow diversification.

Cumulative liquid asset drawdown risk is top-of-mind for many CIOs as it reflects how a prolonged period of poor portfolio performance might lead to a sustained liquid asset drain that increases portfolio's liquidity risk. Replacing 10pp of PE fund allocation with 10pp infrastructure asset investments (PortB) reduces drawdown risk. For example, the 1y average liquid asset maximum drawdown improves from -15.5% of PortA to -15.0% of PortB.

Although portfolio horizon performance is lower for PortB and PortC compared to PortA, adding infrastructure offers CIOs the opportunity to improve their portfolio's tradeoff between performance and liquidity risk. The OASIS framework is flexible and customizable to incorporate a CIOs' unique exposure to infrastructure investments such as investment vehicle types, sector exposures, *etc*. Alternatively, CIOs can specify their own scenarios table to examine the portfolio performance-liquidity tradeoff with varied allocations to infrastructure.

45 See Appendix A10.

Figure 32: Portfolio Performance and Liquidity Risk

OASIS Output

<table>
<tr><th colspan="3"></th><th>PortA
30% Private Equity</th><th>PortB
20% PE + 10% Direct Infra Asset Investment</th><th>PortC
20% PE + 10% Infra Funds</th></tr>
<tr><td>Horizon Performance</td><td colspan="2">Avg. Horizon “Return”</td><td>6.1%</td><td>5.7%</td><td>5.6%</td></tr>
<tr><td colspan="3">Probability of Rebalancing Failures</td><td>9.3%</td><td>1.8%</td><td>8.0%</td></tr>
<tr><td colspan="3">Probability of Selling 3.5pp Liquidity Assets</td><td>8.5%</td><td>1.2%</td><td>6.0%</td></tr>
<tr><td rowspan="4">Cash Flow (Income Return) Variability</td><td rowspan="2">Quarterly Income Return Mean</td><td>Infrastructure</td><td></td><td>2.3%</td><td>1.7%</td></tr>
<tr><td>Private Equity</td><td colspan="3">2.5%</td></tr>
<tr><td rowspan="2">Quarterly Income Return Volatility</td><td>Infrastructure</td><td></td><td>0.9%</td><td>1.9%</td></tr>
<tr><td>Private Equity</td><td colspan="3">2.7%</td></tr>
<tr><td rowspan="4">1y Liquid Assets Drawdown</td><td colspan="2">Avg. Frequency of Violation over 10y (-5% threshold)</td><td>18.9%</td><td>17.4%</td><td>19.2%</td></tr>
<tr><td colspan="2">Avg. Frequency of Violation over 10y (-10% threshold)</td><td>10.3%</td><td>9.1%</td><td>10.3%</td></tr>
<tr><td colspan="2">Avg. Maximum Drawdown %</td><td>-15.5%</td><td>-15.0%</td><td>-15.5%</td></tr>
<tr><td colspan="2">Expected Worst 5% Max-Drawdown</td><td>-34.8%</td><td>-33.2%</td><td>-34.5%</td></tr>
</table>

Note: 5,000 market simulation paths. Horizon return reflects the terminal wealth of the portfolio after deducting liquidity obligations. Probability of rebalancing failures captures the possibility of at least one rebalancing failure (*i.e.*, unable to rebalance within the target asset allocation range at a given quarter) during the 10y investment horizon. Cumulative drawdown of liquid assets over a k-month period is the percentage change of the value of liquid assets over the k-month period. Only negative drawdown numbers are included. For each market simulation path and for a given k, we calculate 120 k-month drawdowns over 10y. The expected frequency of liquid asset drawdown over k-months exceeding a given threshold is the average frequency over the 5,000 simulation paths. The average max-drawdown % of assured cash is the average of 5,000 k-month max-drawdowns with each k-month drawdown being the maximum for each simulation run. The expected worst 5% Max-Drawdown is the average of the 5% (or 25) worst k-month drawdowns. Source: Datastream, Burgiss, EDHEC*infra*, PGIM IAS. Provided for illustrative purposes only.

Summary

We highlight important differences between infrastructure assets and funds and then compare their historical performance and cash flow characteristics with public assets and other private funds. We examine the sensitivity of infrastructure assets and fund performance to public markets by regressing infrastructure (at the aggregate, sector and age group level) annual total returns on public assets annual total returns.

We also investigate how interconnections among infrastructure asset sectors, business risks and corporate structures drive their risk-return profiles. We highlight that a CIO cannot ignore the high idiosyncratic risk of infrastructure assets (even within a given sector) when evaluating their future performance and cash flow risk. We define measures to quantify both idiosyncratic and time-series volatility. We also distinguish between existing and prospective infrastructure investments and their relationship with the public market environment.

To help CIOs make better-informed decisions regarding allocations to infrastructure, we develop a method to estimate an infrastructure asset's periodic cash flows depending on its age and sector that captures the degree of income persistence of over the asset's lifespan.

Finally, we apply PGIM IAS' cash flow-based, asset-allocation framework (OASIS) to portfolios with different allocations to infrastructure and other private assets and quantify how infrastructure investments, with their relatively large income return component, might not only improve portfolio diversification but also liquidity.

Acknowledgements

*We wish to thank, in alphabetical order: Aili Chen (PGIM IAS), Alexander Dotov (TIAA), Anina Fraser (PGIM), Abhishek Gupta (*EDHEC*infra), Debra Hemsey (PGIM Private Capital), Dr. Taimur Hyat (PGIM), Ding Li (GIC), Dr. Grace (Tiantian) Qiu (GIC) and Dr. Tim Whittaker (*EDHEC*infra) for their valuable contributions to this research.*

References

Amenc, N., F. Blanc-Brude, and A. Gupta (2021). "Strategic Asset Allocation with Unlisted Infrastructure: Better Data for Sensible Results." EDHEC*infra*.

Andonov, A., B. Kraussl, and J. Rauh (2021). "Institutional Investors and Infrastructure Investing." Discussion Paper DP 15946 Center for Economic Policy Research.

Blanc-Brude, F., A. Gupta, L. Lu, and A. Wee (2021). "The Volatility of Unlisted Infrastructure Investments: Valuation Drivers and Trends, 2000-2021." EDHEC*infra*.

Blanc-Brude, F., M. Hasan, and T. Whittaker (2016). "Revenue and Dividend Payouts in Privately-held Infrastructure Invetments: Evidence from 15y of UK Data." EDHEC*infra*.

Clark, M.T., and A. Biskupska-Haas (2017). "Open-end *vs.* Closed-end Real Estate and Infrastructure Funds." The Real Estate Finance Hournal.

Dynkin, L., A. Gould, J. Hyman, V. Konstantinovsky, and B. Phelps (2007). *Quantitative Management of Bond Portfolios.* Princeton University Press.

EDHEC*infra*. (2021). "The Fair Value of Investments in Unlisted Infrastructure Equity: The Robustness of Better Data & Advanced Methods."

EDHEC*infra*. (2022). "The Infrastructure Company Classification Standard." EDHEC Infrastructure Institute. https://docs.edhecinfra.com/display/TICCS

Inderst, G. (2009). "Pension Fund Investment in Infrastructure." *OECD Working Papers on Insurance and Private Pensions*, No. 32, OECD Publishing. © OECD. doi: 10.1787/227416754242

Preqin (2021). "2021 Preqin Global Infrastructure Report."

Probitas Partners (2018). "Infrastructure Investing: The Closed-End Fund Market."

Weber, B., M. Staub-Bisang, and H. W. Alfen (2016). "Infrastructure as an Asset Class: Investment Strategy, Sustainability, Project Finance and PPP," 2nd ed.. Wiley.

Shen, J. (2020). "Riders in the Storm: How Volatility Events Affect Private Asset Class Performance." PGIM IAS.

Shen, J., D. Li, G. Qiu, V. Jeet, M. Teng and K.C. Wong (2021). "Asset Allocation and Private Market Investing." *Journal of Portfolio Management,* 2021 47 (4) 71-82; DOI: https://doi.org/10.3905/jpm.2021.1.211.

Shen, J., and M. Teng (2021). "Harnessing the Potential of Private Assets: A Framework for Institutional Portfolio Construction." PGIM IAS.

Shen, J., and M. Teng (2021). "The Rebalancing Conundrum Private Equity Valuations and Market Dislocations." PGIM IAS.

Takahashi, D., and S. Alexander (2002). "Illiquid Alternative Asset Fund Modeling." *Journal of Portfolio Management*, 28 (2). 90- 100. DOI: https://doi.org/10.3905/jpm.2002.319836

APPENDIX

A1. Comparison of Open-end and Closed-end Funds

Figure A1: Closed-end *vs.* Open-end Infrastructure Funds

	Closed-end Funds	Open-end Funds
Liquidity	Committed capital is locked-up for the term of the fund	Have no specific term and may allow for quarterly subscriptions and redemptions (may still subject to lock-up periods for redemption)
Exposure to J-curve	New money is subject to J-curve effect	New money is immediately exposed to the entire portfolio and any income generated from it, and less prone to J-curve effect
Income *vs.* capital gains	Manager actively manages assets to create value and maximizes returns (including capital gain) before the end of the fund's term	Maximize cash flows over the long-term; more income-oriented and value-oriented
Valuation	Investors returns are based on cash flows and final asset sales at market value	Investors invest/redeem based on unrealized assets values. Investors in the same fund may achieve different holding period returns depending on the timing of their investments/redemptions.

Source: Thomson Reuters (See Clark and Biskupska-Haas, 2017), PGIM IAS. Provided for illustrative purposes only.

A2. Review of EDHEC*infra*'s Data Collection and Asset Pricing Methodology

EDHEC*infra's* Data Collection and Infrastructure Universe Standard Brief Review[46]

EDHEC*infra* uses "The Global Infrastructure Company Classification Standard" (TICCS®) – a proprietary taxonomy – to classify and organize data about equity and debt investments in infrastructure companies. Figure A2 shows the four TICCS pillars.

Figure A2: TICCS – Four Pillars

Business Risk	Industrial Activities - Super Class	Geo-Economic Exposures - Regions	Corporate Governance
Contracted	Power Generation x-Renewables	Americas	Project Companies
Merchant	Environmental Services	Asia	Corporates
Regulated	Social Infrastructure	Europe	
	Energy and Water Resources	Oceania	
	Data Infrastructure		
	Transport		
	Renewable Power		
	Network Utilities		

Source: EDHEC*infra*. Provided for illustrative purposes only.

The investable universe is defined according to the "Unlisted Infrastructure Universe Standard" whose objective is to identify the relevant universe (*i.e.,* principal or most advantageous market – IFRS 13) to track the fair value and the risk-adjusted performance of the unlisted infrastructure asset class. The investment universe relevant to measuring performance in the principal market is defined in two steps:

1. **National-market inclusion criteria**: including a minimum number or volume of primary and secondary market trades; a minimum size relative to the existing broad market universe; and a minimum level of audited financial information about the relevant investable infrastructure companies in the market

46 For details please refer to *https://docs.edhecinfra.com/display/UN/Market+Inclusion+Criteria* and *https://docs.edhecinfra.com/display/TICCS*

2. **Individual-company inclusion criteria**: including "investability"; TICCS qualification; infrastructure revenues (higher than 70% of company's revenue comes from infrastructure-related activities); minimum data availability (*e.g.,* companies named and identified, key start dates including incorporation, financial close *etc.*); and minimum total assets book value ($500,000).

Once the investment universe is defined, a sample (or index) universe that meets certain minimum representative criteria is built and used as the basis for defining the constituents of the global broad market index, producing a sample universe of more than 650 infrastructure companies from 25 most active global markets. The **Sample (or Index) Universe** inclusion criteria include:

- 50% coverage of market size by total asset book value ($) (> $1m market value on each rebalancing date);
- Representative of country, broad industrial sector and business-model share of the universe;
- Minimum company-level available data to compute performance (*e.g.,* initial and secondary market prices or credit spreads and audited account including description of the company's financial structure over time);
- Minimum age: typically, 5y post operation start to ensure sufficiently robust estimated of the future cash flows on which the valuation approach relies; and
- Minimum 1y maturity from the rebalancing date.

EDHEC*infra's* Unlisted Infrastructure Asset-Pricing Methodology[47]

Figure A3 shows the systematic risk factors to estimate the equity risk premium and credit spread, along with several control (dummy) variables that account for sector and business model specific effects.

EDHEC*infra* estimates the fair market values of each index constituent (*i.e.,* an asset or company, not a fund) using a discounted cash flow (DCF) approach (A1) that requires cash flows (or dividend plus shareholder loan repayments) forecast at the time of valuation ($Cash\ Flow_{i,t}$) based on company-level information, the term structure of interest rates (rf_t) and an estimated equity risk premia ($\hat{\gamma}_i$) for equity investments (credit spread for debt investments) with a calibrated factor model (A2).

$$P_i = \sum_{t=1}^{T} \frac{Cash\ Flow_{i,t}}{(1+rf_t+\hat{\gamma}_i)^t} \tag{A1}$$

$$\hat{\gamma}_i = \sum_k \widehat{\lambda_{k,i}} \beta_{i,k} \tag{A2}$$

$\hat{\gamma}_i$: $estimated\ mark-to-market\ risk\ premia\ of\ asset\ i$

$\widehat{\lambda_k}$: estimated from regressing expected excess return against individual asset j's factor loadings

$$E(\widetilde{R_j}) - R_f = \lambda_1 \beta_{j,1} + \ldots + \lambda_K \beta_{j,K} + \omega_j \tag{A3}$$

$E(\widetilde{R_j})$: an estimate of the expected return (or IRR) for asset j based on observed primary/secondary price (P_j)

i: all assets including those assets for which no transaction prices were available at the time

j: assets whose primary and secondary transactions are observable in the market at time t

k: $total\ number\ of\ factors$

$\beta_{i,k}, \beta_{j,k}$: $asset\ i\ or\ j's\ factor\ loadings\ on\ factor\ k$

ω_j: the measurement noise introduced when estimating $E(\widetilde{R_j})$

Figure A3: EDHEC*infra* Choice of Risk Factors for Unlisted Infrastructure Equity and Debt

	Unlisted Infrastructure Equity
Factor Name	**Factor Definition**
Size	Total assets
Profit	Return on assets before tax
Investment	Capex *over* total assets
Leverage	Total senior liabilities *over* total assets
Term	20y *minus* 3m public bond yield
Business Risk	Merchant, Regulated or Contracted
Sectors	Industrial activity superclass

	Unlisted Infrastructure Debt
Factor Name	**Factor Definition**
Size	Outstanding face value
Maturity	Maturity
Credit Risk	Probability of default
Short Term Rates	3m interest rate
Business Risk	Merchant, Regulated or Contracted
Sectors	Industrial activity superclass

Source: EDHEC*infra*. Provided for illustrative purposes only.

47 For details of the Unlisted infrastructure Asset-Pricing Methodology, please refer to https://docs.edhecinfra.com/display/AP/Asset+Pricing.

A3. EDHEC*infra* Index Description and Definition

Yellow fields indicate EDHEC*infra* infrastructure equity indices while blue fields indicate EDHEC*infra* infrastructure debt indices.

Figure A4: EDHEC*infra* index Definition and Description

Index (USD unhedged)	Definition
EDHEC*infra* Broad Market Unlisted Equity Index	The index measures the performance of unlisted infrastructure equity investments in the global infrastructure market. Detailed EDHEC*infra* index eligibility criteria defined the constituents of the global broad market index. As of June 2022, the index had a market capitalization of $284.7b with 553 constituents
EDHEC*infra* Broad Market Unlisted Equity Indices by Sectors (equally-weighted)	• The **Power Generation x-Renewables** Index. As of June 2022, the index had a market cap of $24.8b, with 60 constituents. • The **Social Infrastructure** Index. As of June 2022, the index had a market cap of $6.9b, with 67 constituents. • The **Energy and Water Resources** Index. As of June 2022, the index had a market cap of $27.8b, with 32 constituents. • The **Transport** Index. As of June 2022, the index had a market cap of $124.9b, with 181 constituents. • The **Renewable Power** Index. As of June 2022, the index had a market cap of $22.9b, with 134 constituents. • The **Network Utilities** Index. As of June 2022, the index had a market cap of $70.3b, with 52 constituents.
EDHEC*infra* Broad Market Unlisted Equity Indices by Business Risks (equally-weighted)	• The **Contracted** Index. As of June 2022, the index had a market cap of $75.0b, with 330 constituents. • The **Merchant** Index. As of June 2022, the index had a market cap of $94.6b, with 131 constituents. • The **Regulated** Index. As of June 2022, the index had a market cap of $115.1b, with 92 constituents.
EDHEC*infra* Broad Market Unlisted Equity Indices by Corporate Structures (equally-weighted)	• The **Project Company** Index. As of June 2022, the index had a market cap of $101.9b, with 420 constituents. • The **Corporate** Index. As of June 2022, the index had a market cap of $182.8b, with 133 constituents.
EDHEC*infra* Global Unlisted Infrastructure Equity Age Bucket Indices (equally-weighted)	• The **Age 0-10y** Index. As of June 2022, the index had a market cap of $15.5b, with 65 constituents. • The **Age 10y+** Index. As of June 2022, the index had a market cap of $269.2b, with 488 constituents.
Infra300 (equally-weighted)	The index measures the quarterly performance of 300 unlisted infrastructure equity investments in both corporates and project companies. The constituents are selected to form a representative sample by TICCS categories of an underlying universe of close to 6000 firms in 22 countries. The index is equally weighted to minimize the impact a few large firms and better represents the market accessibility to the average investor. infra300 is constructed to track the TICCS of the investable universe. As of June 2022, the index had a market cap of $217.6b.
Infra100® Core (equally-weighted)	The infra100 Core equity index represents the performance of the largest 100 unlisted infrastructure companies in the Core segment of the global unlisted infrastructure market. The core infrastructure index consists of companies whose expected return are less than the median expected return (first two quartiles in the distribution) of the entire EDHEC*infra* universe at each quarter throughout the history. As of June 2022, the index had a market cap of $94.4b.
Infra100® Core+ (equally-weighted)	The infra100 Core+ equity index represents the performance of the largest 100 unlisted infrastructure companies in the Core+ segment of the global unlisted infrastructure market. The core+ infrastructure index consists of companies whose expected return is greater than the median but less than the third quartile (75th percentile) of the expected return of the entire EDHEC*infra* universe at each quarter throughout the history. As of June 2022, the index had a market cap of $95.8b.
Infra100® Opportunistic (equally-weighted)	The infra100 Opportunistic equity index represents the performance of the largest 100 unlisted infrastructure companies in the Opportunistic segment of the global unlisted infrastructure market. The Opportunistic segment consists of companies with expected return greater than the third quartile (75th percentile) of the expected return in the entire EDHEC*infra* universe at each quarter throughout the history. As of June 2022, the index had a market cap of $80.6b.
Infra300® Debt	The Infra300 Debt index represents the performance of the most recent senior debt instruments issued by the constituents of the infra300 index. As of June 2022, the index had a market cap of $82.89b.
EDHEC*infra* Broad Market Private Infrastructure Debt Index	The index measures the performance of unlisted infrastructure debt investments in both corporates and project companies in the global infrastructure market. Detailed EDHEC*infra* index eligibility criteria defined the constituents of the global broad market index. As of June 2022, the index had a market cap of $212.9b with 1148 constituents.

Note: For details of EDHEC*infra* index eligibility criteria please refer to *https://docs.edhecinfra.com/display/IM/Eligibility+Criteria* and *https://docs.edhecinfra.com/display/ID/Eligibility+Criteria*. Source: EDHEC*infra*. Provided for illustrative purposes only.

A4. Unlisted Infrastructure Assets & Funds – Performance Sensitivity Analysis to Public Markets

Regression Analysis – Infrastructure *vs.* Public Assets – Quarterly Total Returns

We regress infrastructure asset and fund quarterly total returns on contemporaneous and 1Q-lagged quarterly public market total returns, along with a "Pre-2015" dummy variable. Figure A5 shows the OLS regression results. For infrastructure funds, public equity coefficients of both the contemporaneous and 1Q-lagged quarterly return are significant. Unexpectedly, for infrastructure equity assets we find both public equity coefficients are significant as well, even though both infrastructure equity asset and public equity quarterly returns do not exhibit any autocorrelation.

Figure A5: Infrastructure *vs.* Public Assets Quarterly Total Returns; OLS Regression
(2006 – 2021; Quarterly Returns, USD unhedged)

Quarterly Total Return	Constant	Public Debt (10y Treasury)	Public Debt (10y Treasury 1Q-lagged)	Public Equity (MSCI ACWI)	Public Equity (MSCI ACWI 1Q-lagged)	Pre-2015 Dummy
Dependent Variable	Infrastructure Equity Asset (infra300 Index)					
adj-R^2	30%					
coefficient	-0.01	0.80	0.06	0.41	0.36	0.03
t-stat	-0.93	3.47	0.28	3.70	3.24	1.88
p-value	35%	0%	78%	0%	0%	6%

Quarterly Total Return	Constant	Public Debt (10y Treasury)	Public Debt (10y Treasury 1Q-lagged)	Public Equity (MSCI ACWI)	Public Equity (MSCI ACWI 1Q-lagged)	Pre-2015 Dummy
Dependent Variable	Infrastructure Debt Asset (Infra300 Debt Index)					
adj-R^2	41%					
coefficient	-0.01	0.38	0.05	0.36	0.03	0.01
t-stat	-1.16	3.50	0.49	6.83	0.63	1.25
p-value	25%	0%	62%	0%	53%	22%

Quarterly Total Return	Constant	Public Debt (10y Treasury)	Public Debt (10y Treasury 1Q-lagged)	Public Equity (MSCI ACWI)	Public Equity (MSCI ACWI 1Q-lagged)	Pre-2015 Dummy
Dependent Variable	Infrastructure Fund IRR					
adj-R^2	42%					
coefficient	0.01	-0.01	0.15	0.25	0.12	0.00
t-stat	2.01	-0.11	1.46	5.22	2.42	-0.30
p-value	5%	91%	15%	0%	2%	77%

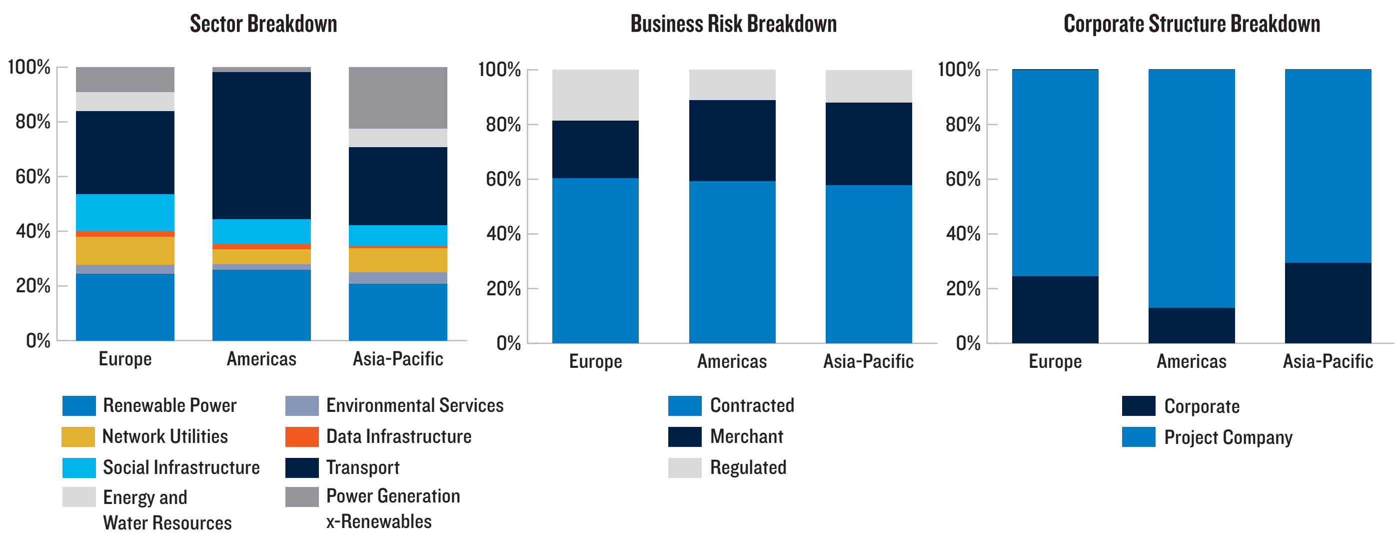
Note: We use Burgiss reported quarterly IRRs (net of fees, USD unhedged) to represent the periodic total returns of private asset LP performance. Indices shown in the figure include: S&P US Treasury Bond Current 10y Index, MSCI All Country World Total Return Index, infra300 Index and Infra300 Debt Index. All returns are USD unhedged. Source: EDHEC*infra*, Datastream, Burgiss, PGIM IAS. Provided for illustrative purposes only.

A5. Risk-Return Profile of EDHEC*infra* Regional Unlisted Infrastructure Equity Index

Figure A6 shows a breakdown of the Broadmarket Unlisted Infrastructure Equity Regional Indices by sector, business risk and corporate structure. As of Q4 2021, *Transport* has a highest data representation in Americas (54%) compared to Europe (31%) and Asia-Pacific (28%). Meanwhile, *Power Generation x-Renewables* has a highest data representation in Asia-Pacific (22%) compared to Europe (9%) and Americas (2%). However, we note that EDHEC*infra* database is more concentrated in Europe (representing close to 70% of the regional exposure of EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Index) and therefore the sector/business risk/corporate structure breakdown could change as it builds data coverage outside Europe.

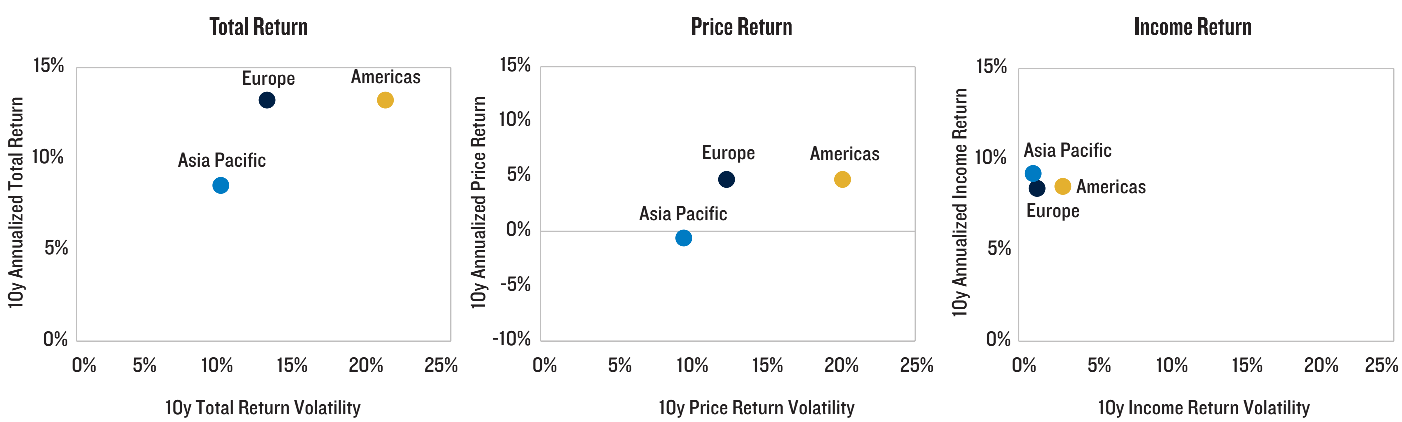
Figure A7 shows the 10y annualized total returns, price returns and income returns and their volatilities for the EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Regional Indices. Income returns, a large component of total returns for all three regions, are rather close.

Figure A6: Regional Infrastructure Index Breakdown
(EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Regional Index; USD unhedged)



Source: PGIM IAS, EDHEC*infra*. As of Q4 2021. Provided for illustrative purposes only.

Figure A7: Unlisted Infrastructure Equity Risk & Return, by Region
(EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Annual Returns; USD unhedged)



Note: Each dot represents the 10y annualized total/price/income return and volatility of Broadmarket Unlisted Infrastructure Equity Region Index (equally-weighted, USD unhedged). Period 2012 to 2021. As of Q4 2021, Europe/Asia Pacific/Americas represents 69.8%/20.6%/9.6%, respectively, of the regional exposure of EDHEC*infra* Broadmarket Unlisted Infrastructure Equity Index (equally-weighted, USD unhedged). Source: PGIM IAS, EDHEC*infra*. Provided for illustrative purposes only.

A6. Global Infra Funds *vs.* US PE Funds – TA Model Parameter Comparison

We use the Takahashi and Alexander (TA) model to estimate private equity valuations (*i.e.*, NAVs) and cash flows (*i.e.*, contributions and distributions) for each vintage commitment, as follows:

Contribution Model:

$$C_t = UC_{t-1} \times \boldsymbol{RC}(Age_{t-1}), \tag{A5}$$

UC_{t-1}: uncalled capital amount at the end of the last period
Age: years since the first capital call
RC (Rate of contribution): a piecewise constant function of age of commitment

Distribution Model:

$$D_t = NAV_{t-1} \times (1 + \boldsymbol{G}) \times \mathrm{RD}(Age_{t-1}, \boldsymbol{bow}, \boldsymbol{L}) \tag{A6}$$

$$\mathrm{RD} = Max[\,Yield, \left(\frac{Age_{t-1}}{L}\right)^{\boldsymbol{bow}}] \tag{A7}$$

NAV Model:

$$NAV_t = NAV_{t-1} \times (1 + \boldsymbol{G}) + C_t - D_t \tag{A8}$$

Figure A8 compares the calibrated TA parameters for historical vintage funds. Estimated *bows* are similar for US buyout funds and global infrastructure funds. *RCs* are slightly higher (indicating quicker capital calls) for global infrastructure funds than US buyout funds. For historical vintage commitments, *Gs* are historical reported lifespan IRRs.[48] *Gs* of global infrastructure funds are markedly lower than those for US buyout funds.

Figure A8: Calibrated TA Parameters

Historical US Buyout and Global Infrastructure Funds

Vintage	Bow		Quarterly Rate of Contribution (RC)						Growth	
			Age: <4q		Age: 4 - 8q		Age: >8q			
	US Buyout	Global Infra	US Buyout	Global Infra	US Buyout	Global Infra	US Buyout	Global Infra	US Buyout	Global Infra
2006	4.6	5.1	8%	18%	11%	12%	10%	11%	8%	2%
2007	5.1	4.0	9%	21%	5%	10%	7%	10%	11%	4%
2008	4.6	3.8	5%	19%	3%	7%	8%	10%	15%	9%
2009	3.7	3.6	3%	6%	6%	3%	9%	10%	19%	7%
2010	4.3	4.7	6%	10%	5%	4%	9%	7%	14%	7%
2011	4.3	3.9	7%	12%	5%	3%	8%	9%	17%	7%
2012	3.8	3.8	7%	7%	4%	4%	10%	9%	19%	12%
2013	3.8	3.5	3%	8%	5%	11%	8%	17%	17%	9%
2014	3.3	3.0	7%	5%	6%	2%	10%	9%	17%	11%
2015	2.9	2.7	6%	9%	6%	12%	11%	16%	17%	11%
2016	2.6	2.9	7%	8%	8%	6%	15%	20%	17%	9%
2017	2.3	3.1	6%	17%	10%	13%	16%	18%	22%	9%

Source: Burgiss, PGIM IAS. As of Q4 2021. Provided for illustrative purposes only.

48 For historical vintages having at least 15y of data, we use 15y reported IRRs. For historical vintages having at least 10y of data, we use 10y IRRs as approximations for 15y IRRs. For historical vintages having only 5y of data, we estimate 15y IRRs from 5y IRRs based on the historical empirical relationship.

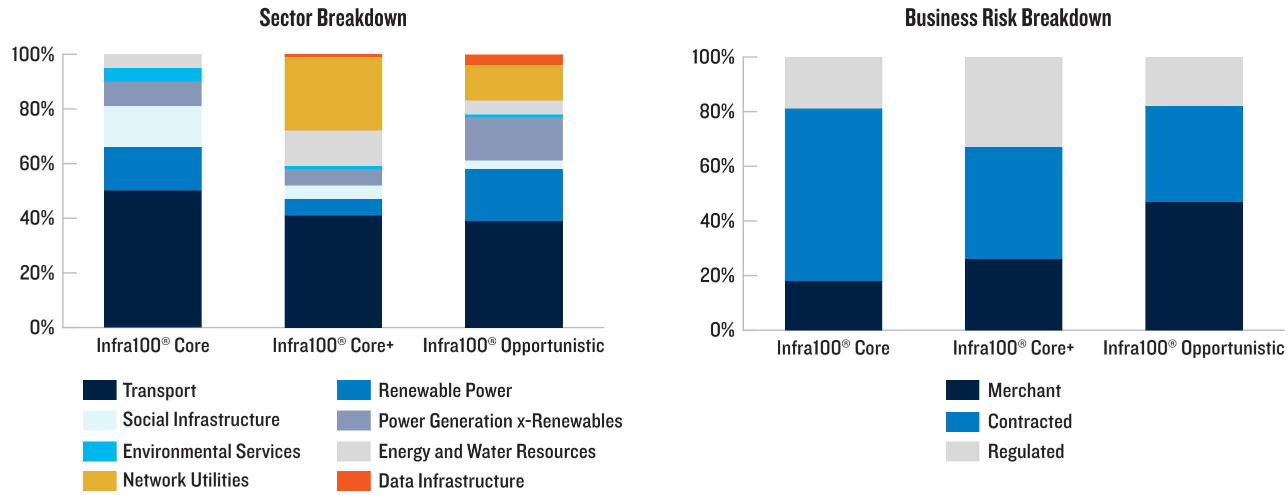
A7. EDHEC*infra* Thematic Strategy Indices, Sectors & Business Risk

Figure A9 shows the sector and business risk breakdown of the *EDHECinfra Core/Core+/Opportunistic* thematic strategy indices. EDHEC*infra* classifies infrastructure assets into *Core*, *Core+* and *Opportunistic* based on their expected return quartile. Differences in sector or business risk compositions of the three strategy indices also reflect differences in sector-specific return expectations.

The *Transport* sector has the following sector weights: Infra100 *Core* Index (50%, the largest sector), *Core+* (41%) and *Opportunistic* (39%). *Network Utilities* and *Energy and Water Resources* have their largest weights within Infra100 *Core+* Index (27% and 13% respectively), followed by *Opportunistic* (13%; 5%) and *Core* (0%; 5%). *Power Generation x-Renewables* has its highest weight in Infra100 *Opportunistic* Index (16%), followed by *Core* (9%) and *Core+* (6%).

In regard to the breakdown of business risk across the three thematic strategy indices, *Contracted* has its highest weight in the Infra100 *Core* Index (63%), followed by *Core+* (41%) and *Opportunistic* (35%). *Merchant* has its highest weight in the Infra100 *Opportunistic* Index (47%), followed by *Core+* (26%) and *Core* (18%).

Figure A9: EDHEC*infra* Thematic Strategy Indices, Sectors & Business Risk



Source: PGIM IAS, EDHEC*infra*. As of Q1 2022. Provided for illustrative purposes only.

A8. Sector Income Return Beta Distribution Parameters

Figure A10: Infrastructure Asset Income Returns, by Sector

Beta Distribution Parameter Calibration

Sector	Alpha (α)	Beta (β)
Power Generation x-Renewables	1.19	7.34
Environmental Services	0.64	4.27
Social Infrastructure	1.37	16.62
Energy and Water Resources	1.31	11.48
Data Infrastructure	0.61	6.01
Transport	0.81	9.29
Renewable Power	0.85	6.89
Network Utilities	1.21	12.33

Note: Underlying annual income returns are from 690 firms in EDHEC*infra* database from Q1 2000 to Q2 2021. Source: EDHEC*infra*, PGIM IAS. As of Q2 2021. Provided for illustrative purposes only.

A9. OASIS Assumptions

Public and Private Assets Capital Market Assumptions

Each market simulation run starts with sampling stock and bond quarterly market returns.[49] Public passive assets exhibit different return and risk characteristics under different market environments (*i.e.,* "good" *vs.* "bad" state of economy). We define a "bad" economy when the monthly moving average (6m, backward-looking) of the S&P 500 simulated cumulative total return experiences a drawdown of more than -15%. Figure A11 shows capital market assumptions for the two public passive assets in different economic environments. We assume public active equity generates an alpha of 100bp/y over market equity returns.

For private equity funds and infrastructure funds, we assume the investor holds US buyout and global infrastructure funds. We rely on the Takahashi and Alexander (TA) cash flow model to generate private asset cash flows that are empirically linked to public market performance. We assume the investor has average fund-selection skill and private equity's future performance relative to public equity (measured by PME benchmarked by MSCI ACWI Index) will the same as the historical relationship suggests, translating to an 18.3% and 13.1% expected return (IRR) for private equity and infrastructure funds, respectively.[50]

Figure A11: Asset Return and Risk Assumptions

	Expected Return		
Economic State	**Total**	**Good**	**Bad**
Public Fixed Income Portfolio	3.0%	2.1%	6.1%
Public Equity	13.7%	16.6%	3.7%
Private Equity Funds	18.3%	-	-
Infrastructure Funds	13.1%	-	-
	Standard Deviation		
Economic State	**Total**	**Good**	**Bad**
Public Fixed Income Portfolio	5.4%	4.9%	6.9%
Public Equity	16.9%	11.6%	30.7%

	Correlation	
	Public Fixed Income Portfolio	**Public Equity**
Public Fixed Income Portfolio	1.00	0.39
Public Equity	0.39	1.00

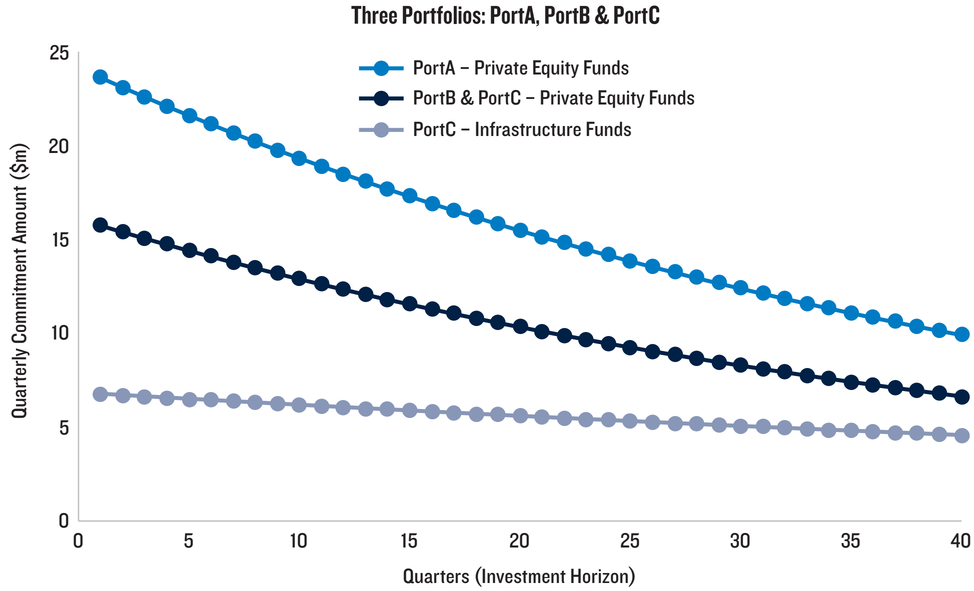
Note: Yellow field indicates an investor input. Capital market assumptions in the table for public fixed income portfolio and passive public equity portfolio are based on historical quarterly performance data of Bloomberg Global Aggregate Total Return Index and MSCI ACWI index data from Q3 2008 to Q3 2021. Source: DataStream, Burgiss, PGIM IAS. Provided for illustrative purposes only.

Private Equity and Infrastructure Funds – Commitment Strategy

Figure A12 shows the assumed quarterly commitment pacing strategy for private equity and infrastructure funds for the hypothetical (AUM $1b) portfolios, PortA, PortB and PortC, respectively, to maintain the expected private equity and/or infrastructure funds allocation over the 10y investment horizon (PortA: 30% PE funds; PortB: 20% PE funds and 10% infrastructure assets; PortC: 20% PE funds and 10% infrastructure funds). In addition, the same commitment pacing strategies are followed (controlled) for each of the 5,000 market simulation runs to ensure consistent comparison of performance and liquidity risk of the three portfolios.

49 See M. Teng and J. Shen (2019) for details on the simulation methodology for public asset returns.
50 See Shen (2021) for more details.

Figure A12: Private Equity and Infrastructure Funds Commitment Strategy Assumptions



Note: We assume AUM of $1b for the foundation portfolio at the inception of the 10y investment horizon in the case study. Source: PGIM IAS. Provided for illustrative purposes only.

Rebalancing Tolerance Range

CIOs might be more concerned if they cannot keep the desired balance between growth assets and public fixed income in their portfolio, rather than the balance between liquid and illiquid growth assets. In this regard, cash, public fixed income portfolio and growth assets portfolio are rebalanced quarterly with the tolerance ranges in Figure A13.

Figure A13: Rebalancing Tolerance Ranges

<table>
<tr><th>Asset Class</th><th>Broad Asset Category</th><th colspan="2">Assumed Tolerance Range (+/-)</th><th>Rebalancing Frequency</th></tr>
<tr><td>Cash</td><td>Cash</td><td colspan="2">0.5%</td><td>Quarterly</td></tr>
<tr><td>Public Fixed Income Portfolio</td><td>LDI</td><td colspan="2">1%</td><td>Quarterly</td></tr>
<tr><td>Passive Public Equity</td><td rowspan="5">Growth</td><td>1%</td><td rowspan="5">4%</td><td rowspan="5">Quarterly</td></tr>
<tr><td>Active Public Equity</td><td>3%</td></tr>
<tr><td>Private Equity Funds</td><td>0%</td></tr>
<tr><td>Direct Infra Assets Investments</td><td>0%</td></tr>
<tr><td>Infrastructure Funds</td><td>0%</td></tr>
</table>

Note: Yellow field indicates an investor input. Source: PGIM IAS. Provided for illustrative purposes only.

Infrastructure Assets Portfolio in PortB

Figure A14: Assumptions of Infrastructure Assets Portfolio in PortB
(At the Beginning of 10y Investment Horizon)

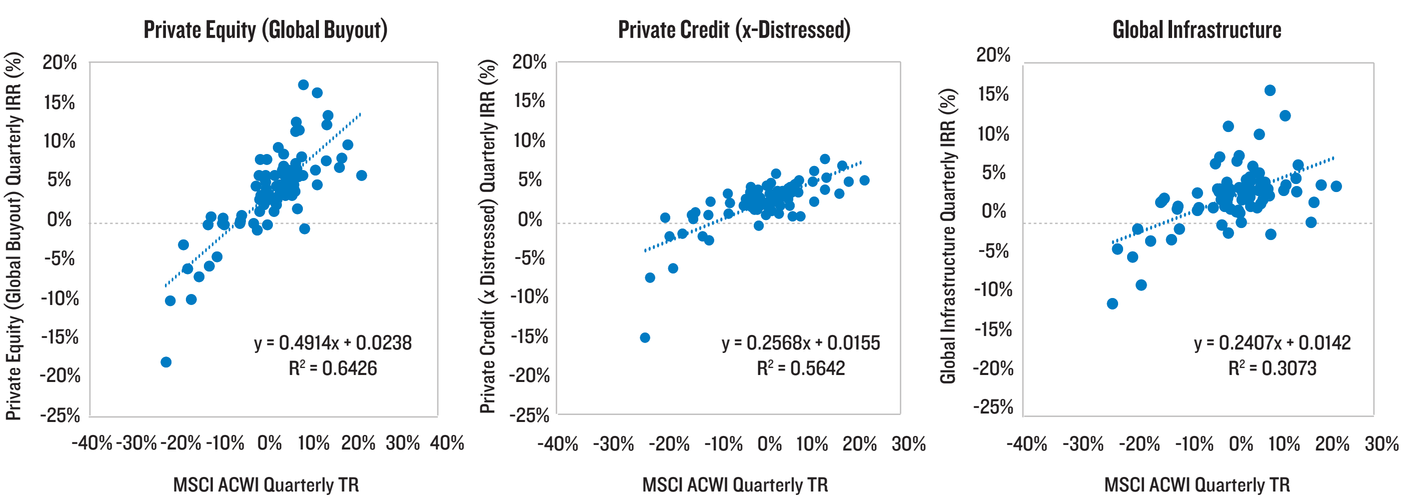
				Assumptions of Existing Investments	
Asset	Sector	Weight (%)	Age (y)	Income Paid?$_{t=0}$	Income Return Quartile $_{t=0}$
1	Power Generation x-Renewables	12%	13	Yes	Q2
2	Power Generation x-Renewables	13%	18	Yes	Q4
3	Transport	4%	19	Yes	Q3
4	Transport	12%	16	Yes	Q4
5	Transport	3%	7	No	Q2
6	Renewable Power	8%	14	Yes	Q2
7	Renewable Power	20%	12	Yes	Q1
8	Renewable Power	10%	6	Yes	Q3
9	Network Utilities	8%	17	Yes	Q3
10	Network Utilities	10%	9	Yes	Q1

Source: PGIM IAS. Provided for illustrative purposes only.

A10. Quarterly and Horizon Returns (by Vintage) of Private Asset Funds *vs.* Public Assets

It is potentially misleading to compare fund and asset performance that use different valuation methodologies. However, to suggest the potential diversification improvement among private asset funds, Figure A15 compares quarterly IRRs of private asset funds with contemporaneous quarterly public equity (MSCI ACWI) total returns since Q1 2001. We find that different private asset funds have varied IRR sensitivity to public equity returns. In addition, Figure A16 shows that private asset fund quarterly IRRs are moderately to highly correlated with each other, suggesting some scope for further portfolio diversification by replacing some PE fund allocation with infrastructure funds.

Figure A15: Private Asset Fund Sensitivity to Public Market Returns
Quaterly IRRs *vs.* Public Equity Quarterly Total Returns



Source: Burgiss, Datastream, PGIM IAS. Period Q1 2001 to Q1 2022. Provided for illustrative purposes only.

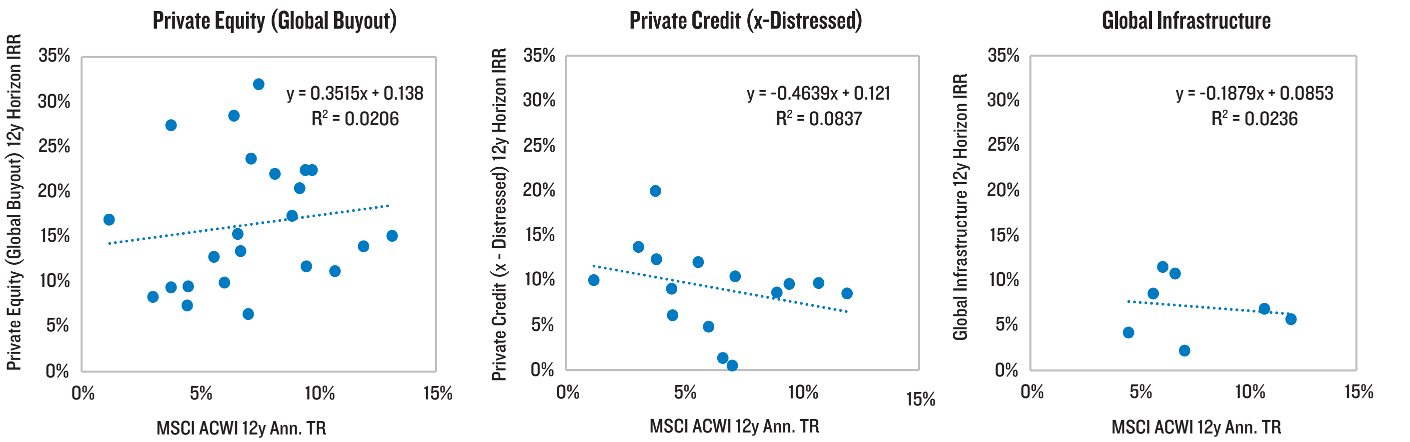
Figure A16: Correlations of Private Asset Funds, Quaterly IRR

	Private Equity (Global Buyout)	Private Credit (x-Distressed)	Global Infrastructure
Private Equity (Global Buyout)	1		
Private Credit (x-Distressed)	0.87	1	
Global Infrastructure	0.75	0.70	1

Source: Burgiss, PGIM IAS. Period QI 2001 to QI 2022. For illustrative purposes only.

In OASIS, cash flows of private asset fund are modeled using the TA model with an annualized lifespan IRR (horizon growth rate) for a fund of a given vintage based on historical relationship between private and public assets (Appendix A6). For example, if the horizon of a 2008-vintage PE fund is 12y, the horizon growth rate is the annualized IRR of the fund from 2008 to 2020. Figure A17 compares the horizon (12y) IRRs of private asset funds with public equity's annualized horizon total returns (over the same period as the lifespan of the fund). With the available data (limited for credit and infrastructure funds), we find that fund horizon IRR sensitivity to horizon public equity returns varies by fund asset type, which in turn implies varied responses of fund cash flows to the public market environment.

Figure A17: Private Asset Funds Horizon IRRs *vs.* Public Equity Horizon Annualized Returns



Note: PE (Global Buyout) horizon (12y) IRRs include vintages starting from 1988 to 2010. Private Credit (x-Distressed) horizon (12y) IRRs include vintages from 1996 to 2010. Global Infrastructure horizon (12y) IRRs include vintages from 2004 to 2010.
Source: Burgiss, Datastream, PGIM IAS. As of QI 2022. Provided for illustrative purposes only.

More Publications from PGIM IAS

Publications

- Measuring the Value of a Portfolio Liquidity Line (*September 2022)*
- Stock-Bond Correlation: A Global Perspective (*June 2022*)
- Super Funds & Master Trusts in a World of Member Switching, Early Release Schemes & Climate Calamities *(March 2022)*
- The Rebalancing Conundrum: Private Equity Valuations and Market Dislocations *(December 2021)*
- A Rising Private Asset Class: Core+ Real Estate Debt *(July 2021)*
- Harnessing the Potential of Private Assets: A Framework For Institutional Portfolio Construction *(June 2021)*
- US Stock–Bond Correlation: What Are the Macroeconomic Drivers? (*May 2021*)
- Equity Portfolio Manager Active Risk and Information Ratio: How Does the Reward Vary with Active Risk? *(November 2020)*
- Building and Maintaining a Desired Exposure to Private Markets – Commitment Pacing, Cash Flow Modeling, and Beyond *(November 2020)*
- Next-Generation Commodity Benchmarks: RASA Benchmarks Designed to Align with CIO Investment Objectives *(November 2020)*
- Modeling Private Investment Cash Flows with Market-Sensitive Periodic Growth *(October 2020)*
- Riders in the Storm: How Volatility Events Affect Private Asset Class Performance *(June 2020)*
- The Probability of Recession: A Critique of a New Forecasting Technique *(June 2020)*
- What's in Your Real Asset Portfolio? *(May 2020)*
- Measuring the Value of LP Fund-Selection Skill *(April 2020)*
- Building a Better Portfolio: Balancing Performance and Liquidity *(joint with GIC Singapore - April 2020)*
- What is the Optimal Number of Equity Managers? A CIO Toolkit for Manager Allocation *(February 2020)*
- Institutional Gold! *(November 2019)*
- A Fair Comparison Framework: Risk and Return in Private & Public Investments *(October 2019)*
- Asset Allocation for "End-State" Portfolios *(September 2019)*
- The Diversity of Real Assets: Portfolio Construction for Institutional Investors *(April 2019)*
- The Tradeoff Between Liquidity and Performance: Private Assets in Institutional Portfolios *(January 2019)*
- Emerging Market Equity Benchmarks for Japanese Investors: Countries, Sectors or Styles? *(October 2018)*
- Forecasting Long-Term Equity Returns: A Comparison of Popular Methodologies *(September 2018)*
- What Can the Markets Tell Us about Future Economic Growth? *(September 2018)*
- How to Measure the Value of Adding a Cross-Sector Manager *(September 2018)*
- Anchor to Windward: Aligning Absolute Return Objectives *(May 2018)*
- When the Dust Flies: How Volatility Events Affect Asset Class Performance *(April 2018)*
- Asset Allocation with Illiquid Private Assets (*February 2018*)
- The Impact of Market Conditions on Active Equity Management *(March 2017)*

Bespoke Client Projects

- How to design a commodity benchmark aligned with a DB plan's objectives?
- Will my equity managers perform as expected in the next downturn?
- How should we allocate capital across our equity managers?

Case Studies

- Cenland Corporation (I) —The CIO and the Closing of the DB Plan *(December 2019)*
- Cenland Corporation (II) — The CIO and the Freezing of the DB Plan *(December 2020)*
- Cenland Corporation (III) – The CIO and the Transition to DC *(December 2021)*

The Differential

- Issue #1: March 2021
- Issue #2: July 2021
- Issue #3: December 2021
- Issue #4: March 2022
- Issue #5: June 2022
- Issue #6: September 2022

PGIM

THE PURSUIT OF OUTPERFORMANCE

IAS 1011-600