Invesco Vision:
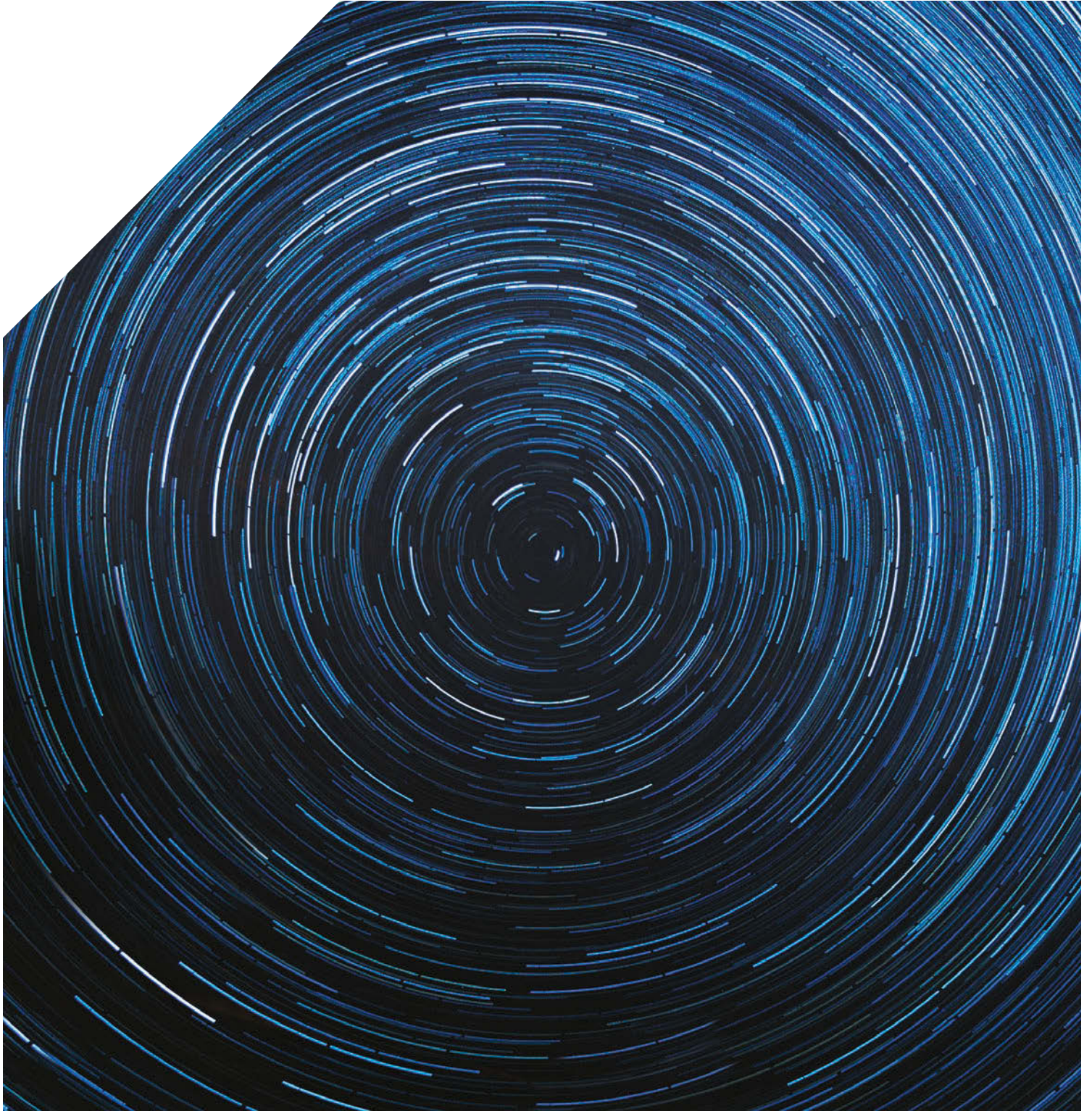Portfolio management decision support system

Invesco Vision is a support system designed to foster better portfolio management decision-making. By helping investors better understand portfolio risks and trade-offs, it helps to identify potential solutions best aligned with their specific preferences and objectives.

In our long experience as global investors, we understand investing to be the art and science of making decisions about the trade-offs between the opportunity for higher returns and the risk of pursuing those returns. Much of that information is not readily available to investors and sometimes those trade-offs are not always evident. To see them, we need the right information.

At the same time, portfolio managers (and often their clients) are increasingly required to be "expert generalists" on an expanding knowledge base that extends well beyond the domain of traditional finance, including technology, advanced quantitative methods, geopolitics and regulations. We believe portfolio management will only become more demanding, as technology advances, data proliferates and the financial markets continue to evolve.

This is why Invesco Investment Solutions (IIS) developed Invesco Vision: a decision support system for our clients and researchers, offering a broad set of capabilities intended to better understand the risks and trade-offs presented by assets and portfolios, and to identify solutions that are best aligned with investors' specific preferences and objectives.

Invesco Vision combines analytical and diagnostic capabilities into a single solution that supports better decision-making – marrying the strengths of machine efficiency and transparency with human judgment and collaboration.

This executive summary distills the contents of our white paper, which includes the theoretical and mathematical background on the approaches and methods built into Invesco Vision, and 15 case studies that demonstrate how its capabilities can be used to develop a range of practical real-world investment solutions.

Invesco Vision

The IIS team of global research professionals, with expertise across a variety of domains – including mathematics, statistics and data science – has dedicated years of research and effort developing Invesco Vision. The platform was specifically designed around the idea of providing professional investors with the information they need to make better-informed investing decisions. Invesco Vision fosters more productive collaborations with our clients and supports them by more effectively applying their judgment to the portfolios they manage.

This summary and its accompanying white paper provide an overview of Invesco Vision's current capabilities. We are committed to advancing Invesco Vision's capabilities to meet our clients' evolving needs, including enhanced simulations, agent-based modeling and other planned developments.

Invesco Vision simplifies the process of defining the relevant characteristics of assets and liabilities, the most critical component of risk management and portfolio construction.
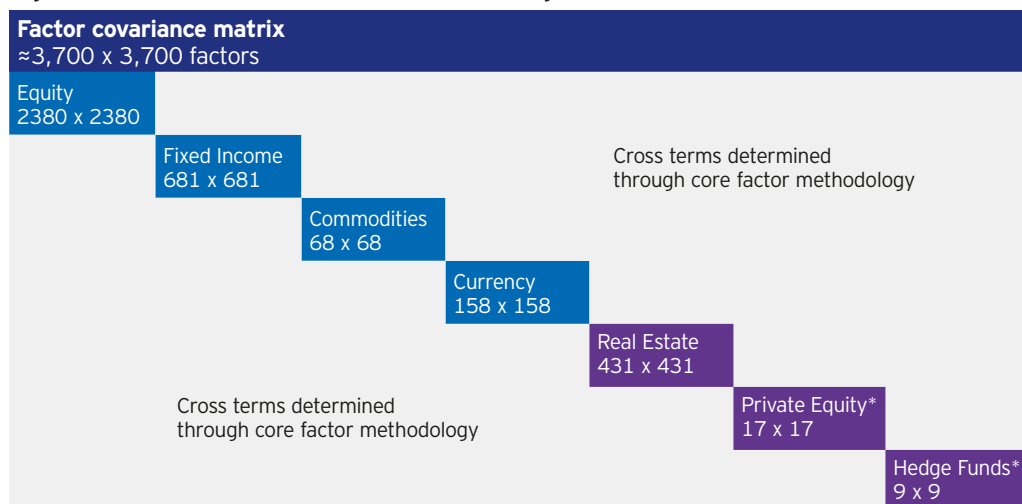
I. Modeling assets and liabilities

Successful investing requires an understanding of asset and market dynamics. The covariance matrix–a model of "how the world works" describes the volatilities of investments under consideration and the relationships between them–is central to risk management and portfolio construction exercises. Within Invesco Vision, we put considerable effort into identifying a multi-factor risk model that could provide a high degree of flexibility in consistently modeling a broad range of assets.

Of the three main modeling frameworks–macroeconomic, statistical factor and fundamental factor models–we chose fundamental factors to model the risk and correlation characteristics of the global collection of comprehensive asset classes and investments built into Invesco Vision. Using fundamental factors provides enormous practical flexibility and allows for an intuitive understanding of the dependence of an asset's returns on well-defined characteristics. Rather than develop a proprietary fundamental risk model, we incorporated BarraOne®, one of the most recognized and respected risk models available, into Invesco Vision.

Our multi-asset fundamental risk model drives Invesco Vision's risk modeling capabilities, using over 3,000 factors that span the major asset classes across various economies, countries and industries, alternative factors shown on Figure 4. Factor modeling often allows us to distill the key performance drivers of any security into a smaller set of relevant systematic factors. (All figure numbers are consistent with their order in the Invesco Vision white paper.)

Figure 4: Factor-based covariance matrix including alternative factors

Factor covariance matrix
≈3,700 x 3,700 factors

Equity
2380 x 2380

Fixed Income
681 x 681

Commodities
68 x 68

Currency
158 x 158

Real Estate
431 x 431

Private Equity*
17 x 17

Hedge Funds*
9 x 9

Cross terms determined through core factor methodology

Cross terms determined through core factor methodology

* Private equity and hedge fund assets get exposure to both traditional asset factors as well as the indicated private factors which are uncorrelated to any other factors.
Source: Invesco, BarraOne.

Invesco Vision models assets through:

- Holdings-based analysis, when the security level holdings of a portfolio are available.
- Returns-based analysis, in cases where information about the underlying portfolio constituents is not available.

Invesco Vision can also model private investments, whose characteristics extend beyond public market factors, including private equity, direct real estate, hedge funds and custom alternative assets. (See Figure C8a, Portfolio construction with alternative assets.)

Figure C8a: Portfolio construction with alternative assets
Comparison of frontiers with alternative investments (scenario frontier) and without (frontier)
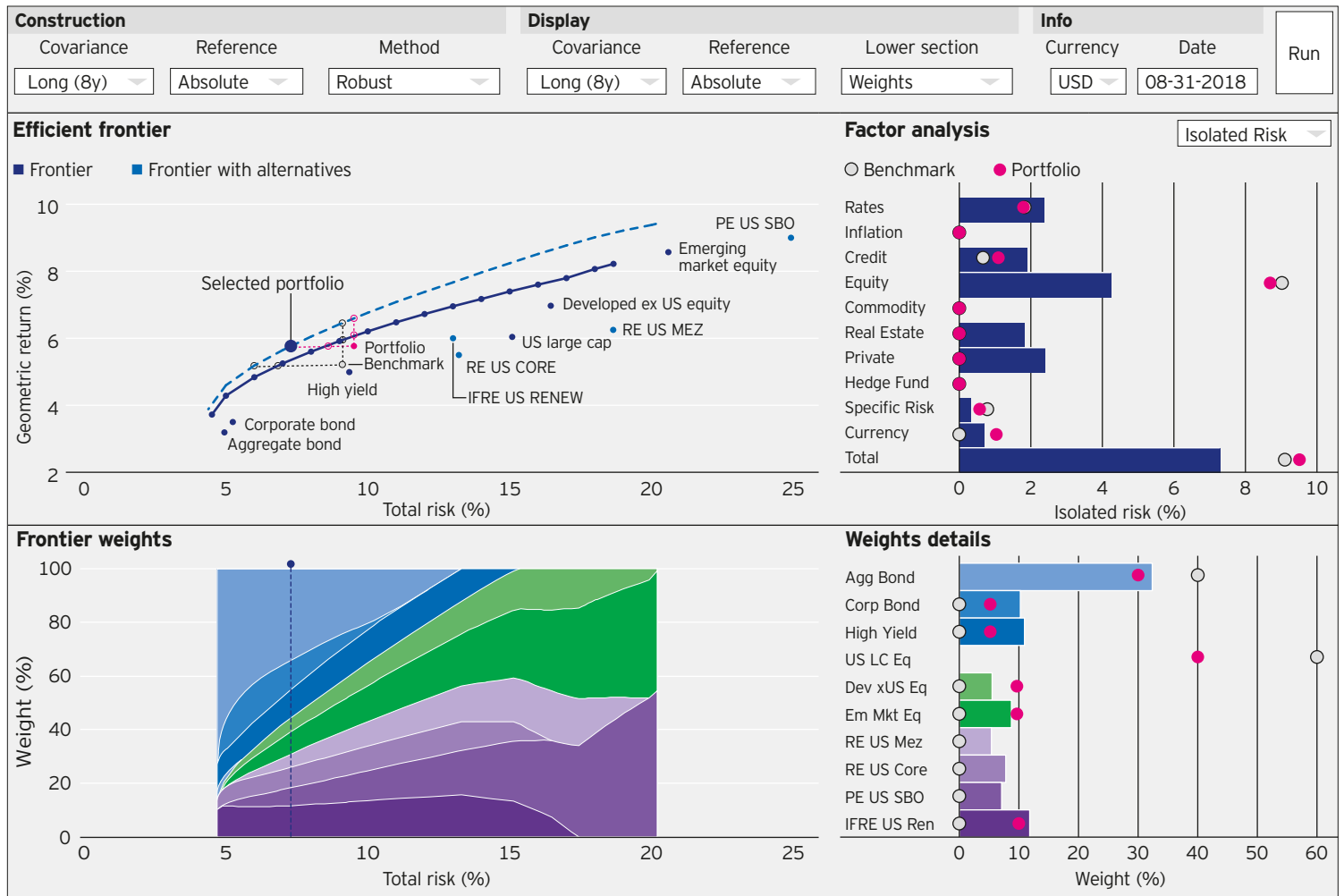
Modeling liabilities
Many investors seek to develop or manage portfolios designed to fund a future stream of cash flows. For these cases, Invesco Vision provides modeling capabilities that are critical for addressing various types of liabilities. Nominal or real discount curves can be used to discount liability streams. For example, nominal yield curves are provided for nominal cash flows and real yield curves for inflation-adjusted cash flows. Investors can also choose to use curves based on sovereign rates, swap rates or corporate rates.

The key to modeling liabilities is understanding how the present value will react to changes in market conditions. Invesco Vision allows for greater insight regarding these dynamics by translating liability streams into a set of factor exposures, just like those for assets.

Regulatory risk models

Invesco Vision also allows insurance entities operating in either the Solvency II or the NAIC framework to develop capital-efficient investment portfolios. Each framework uses its own formulaic methodology for computing the capital charges that will be applied to various asset allocation schemes.

For Europe's Solvency II regulations, Invesco Vision uses the market risk component of the Solvency Capital Requirement (SCR) calculation, which comprises interest rate risk, spread risk, equity risk, property risk, concentration risk and currency risk.

For the US National Association of Insurance Commissioners (NAIC) Risk-Based Capital (RBC) regulations, Invesco Vision can help address the asset risk modules that focus on investment risks associated with fixed income and equity.

Estimating expected returns

To estimate a consistent set of expected returns, Invesco Vision can accommodate investor-defined inputs or leverage Invesco's capital market assumptions (CMAs), which cover a broad number of asset classes across multiple regions of the global economy. In cases where assets do not perfectly align with our CMA asset coverage, we employ a factor-based framework that leverages the underlying factor exposures of our CMA and non-CMA assets.

While expected return inputs for portfolio optimization are necessarily expressed in arithmetic terms, Invesco Vision allows for more intuitive portfolio selection by presenting efficient frontiers in geometric terms.

Currency considerations

Invesco Vision can be used across major currencies, incorporates hedging considerations and addresses cash flows from many different countries.

Objectives and preferences can vary widely from one investor to another. In any case, Invesco Vision can address the main challenge of portfolio construction, understanding and choosing acceptable risk-and-return trade-offs, with a variety of portfolio optimization methods.

II. Portfolio construction

Investors have different objectives and preferences that must be considered as part of the portfolio construction process. However, the main challenges in portfolio construction are identifying a set of acceptable portfolio options, understanding the relevant risk and return trade-offs and making sound, reasoned decisions about those trade-offs to arrive at the portfolio that is most likely to achieve the desired investment outcomes. Invesco Vision facilitates this through a variety of portfolio optimization methods:

Absolute risk optimization when our goal is to minimize the absolute portfolio risk for any given portfolio return, or to maximize expected return for a given level of portfolio risk.

Relative risk optimization when we seek to minimize risk (tracking error) or maximize return (excess return) relative to a specified benchmark or reference asset/portfolio.

Robust mean-variance portfolio optimization addresses concerns regarding the likelihood of errors in the estimation of expected returns–an issue that can result in portfolio allocations that are concentrated in a small number of assets, and can lead to overweighting underperforming assets.

Robust mean-variance portfolio optimization incorporates the uncertainty of expected returns by adding a penalization term to the return target constraint, resulting in asset allocations that are more diversified than those provided by unconstrained. (See Figure 32, Uncertainty ellipsoid showing the distance between the actual and forecasted returns.)

Figure 32: Uncertainty ellipsoid showing the distance between the actual and forecasted returns
The Robust mean-variance optimization process recognizes the uncertainty of actual returns
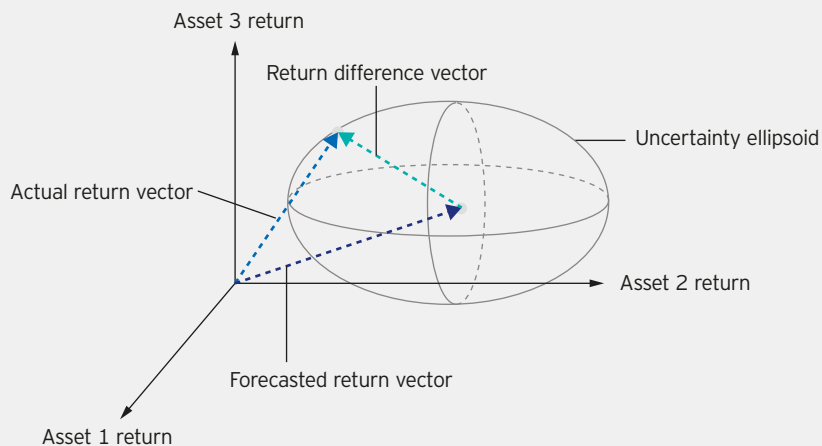
Source: Invesco.

Return agnostic solutions allow investors to consider allocations that don't rely on return forecasts, such as equal weighted, equal volatility, equal risk contribution, maximum diversification, or global minimum variance portfolios. These solutions can provide a unique perspective on portfolio allocations or serve as a reference when constructing portfolios.

Cash flow (liability) matching when an institution or portfolio manager, expected to make a sequence of future cash payments, faces a standard liability matching problem. This generally entails addressing a series of future cash payments that must be made using the principle and coupon payments from a collection of fixed income investments. Invesco Vision allows for the development of both cashflow-driven investing (CDI) and liability-driven investing (LDI) solutions to efficiently address liabilities. (See Figure C5b, Liability-driven investing–US corporate defined benefit plan.)

Multi-period portfolio construction for investors with a long-term investment horizon, who anticipate numerous cash inflows and outflows. An optimal investment strategy will include a "glidepath"–a sequence of time-dependent optimal portfolios. This one strategy can address several objectives: for example, maximizing expected wealth at the end of a 30-year investment horizon subject to various inflows and outflows, while not exceeding a specific level of uncertainty.

Figure C5b: Liability-driven investing – US corporate defined benefit plan
Liability relative efficient frontier
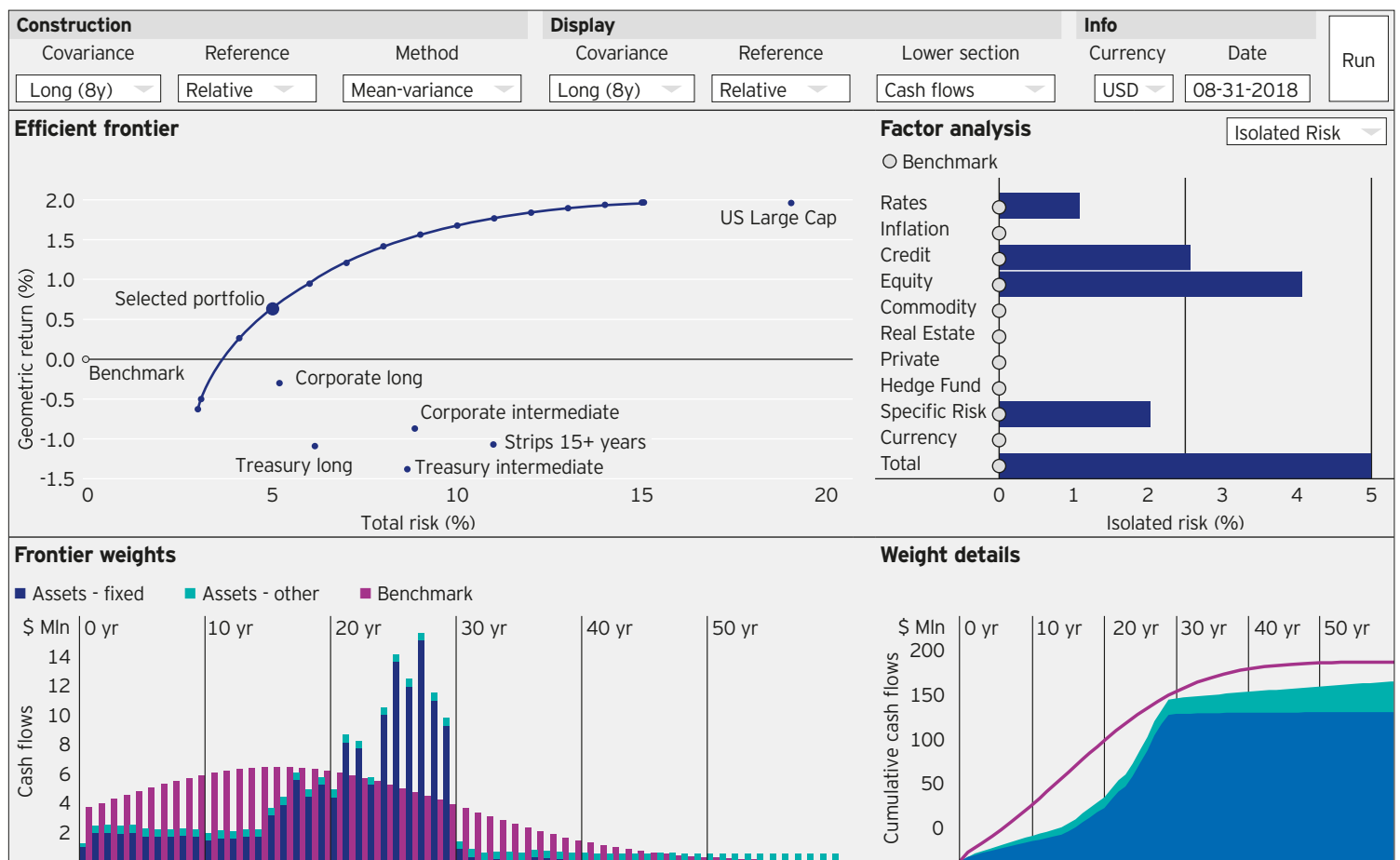
Invesco Vision enables investors to test and evaluate portfolios with a variety of risk and scenario analytics.

III. Portfolio analytics

Whether we are creating a new portfolio or evaluating an existing allocation, gaining a better understanding of the specific risk exposures presented as well as how the portfolio might behave in a number of different scenarios can help inform allocation decisions. Invesco Vision includes the following key analytical tools for portfolio evaluation and selection:

Evaluating factor exposures

To better understand portfolio risk, we need to be able to view risk in a number of different ways. Invesco Vision allows investors to decompose portfolio risk into various underlying factors, including multiple factor groups that allow identification and evaluation of various risks, aggregating or decomposing factor risks to many levels of granularity or relevant groupings. Individual factor risk can also be viewed in isolation and in terms of its contribution to total risk.

Historical and hypothetical scenario analysis

Understanding how a portfolio might have performed during various historical, geopolitical and economic environments, or how it might perform in hypothetical future scenarios, can help inform portfolio management decisions. Invesco Vision enables this by providing detailed decompositions that help to identify key drivers of risk within a portfolio:

- **Historical scenario analysis** can provide insights on the magnitude and direction of a portfolio's returns during historical scenarios of interest (e.g. the 1970s oil crisis, the 1987 market crash, the Global Financial Crisis, Brexit).

- **Hypothetical scenario analysis** can model various future market events including shocks to global equities, US equities, EAFE equities, US Treasuries, currencies, oil and gold.

Invesco Vision also allows users to consider scenarios in correlated terms, where changes in factors are propagated across all other factors, and in uncorrelated terms, where changes are isolated to a specific factor.

A brief overview of the 15 case studies provided in our white paper show how Invesco Vision can be used in practice across a range of portfolio management challenges.

IV. Practical application: Case studies

Finally, our white paper details the following 15 case studies, briefly and graphically showing how Invesco Vision can be used in practice to address the risk and return challenges frequently encountered in the institutional marketplace.

Case 1:	This standard optimization exercise shows how Invesco Vision's capabilities facilitate absolute risk optimization and the ultimate task of selecting a portfolio that is closely aligned with a user's preferences.
Absolute risk optimization *Creating an efficient frontier*	

Case 2:	Invesco Vision can also be used to create portfolios where return and risk are considered relative to a reference investment or benchmark. This case study demonstrates how the optimization exercise can be decoupled from how its results are viewed–important, for example, when investors want to evaluate both the absolute and relative risk characteristics of a portfolio.
Relative risk optimization *Creating a style-premia portfolio*	

Case 3:	Reference portfolios are frequently used by pension plans as baselines for measuring investment performance and managing risk. This case demonstrates how Invesco Vision identifies solutions that are expected to outperform the reference portfolio while minimizing tracking error–particularly useful for plan sponsors and corporate entities that are sensitive to how they are positioned relative to their peers.
Relative risk optimization *Optimizing with a reference portfolio*	

Case 4:	In this example, we consider two efficient frontiers comprising a small set of fixed income and equity indices: one created using unconstrained mean-variance optimization (MVO), the other created using robust mean-variance optimization (RMVO). Specifically, we compare efficient portfolios with an expected return equal to that of an included existing portfolio. In both cases, we find that the same return can be achieved at lower levels of risk. We also find that the RMVO portfolio is expected to achieve its return through a more diverse set of underlying asset and factor exposures.
Robust optimization *Addressing estimation error in portfolio construction*	

Case 5:	This example showcases Invesco Vision's liability stream modeling capabilities, where generic or highly customized liability profiles can be created and used as part of an asset allocation exercise. In this case, it leads to a somewhat counterintuitive solution that best minimizes funding ratio volatility while seeking to exploit the benefits of growth assets.
Liability-driven investing *LDI solutions for US corporate defined benefit plans*	

## Case 6: **Liability driven investing** *LDI solutions for UK defined benefit plans*	A demonstration of Invesco Vision's handling of the more unique characteristics of UK DB plans, which include inflation-linked cash flows in addition to the typical nominal cash flows.
## Case 7: **Cash flow driven investing** *Creating cash flow-matched portfolios*	The case demonstrates how a buy-and-hold portfolio can be created to defease a pre-specified set of liabilities. It highlights Invesco Vision's cash flow optimizer, which ensures that assets don't need to be sold to defease the liabilities. This example also shows how expected cash flows from non-fixed income assets may be included.
## Case 8: **Portfolio construction with alternative assets** *Evaluating opportunities for improved risk-adjusted returns*	Demonstrates how Invesco Vision evaluates the impact of including alternatives, using robust mean-variance optimization. The results are more diversified portfolio allocations that are less susceptible to return estimate uncertainty, and that avoid highly concentrated weights to alternatives that often result because of their attractive risk to return characteristics.
## Case 9: **Portfolio evaluation** *Considering historical and hypothetical scenarios*	In constructing outcome-oriented solutions, clients want to understand how they might perform in various market conditions. This example analyzes performance during historical periods and under various hypothetical market shocks. By decomposing the projected returns into underlying factor components, Invesco Vision allows us to more accurately determine the driving forces behind observed performance, and to use this information to adjust the portfolio. (See Figure C9a, Historical scenarios, and Figure C9b, Hypothetical scenarios on page 12.)
## Case 10: **Currency hedging** *Addressing currency risk*	Features Invesco Vision's ability to work with various base currencies to best represent the interests of clients across various economic regions. By adjusting return expectations to the relevant base currency, and addressing any embedded currency risks, Invesco Vision shows that the impact of switching to a different base currency (combined with full currency hedging) results in a vertical shift of the efficient frontier by a magnitude dictated by the interest rate differential between the two currencies.

Case 11:

Portfolio analysis with regulatory considerations
Solvency II

Shows how Invesco Vision addresses challenges posed by economic risk and regulatory requirements using a UK-based insurer subject to Solvency II. Digging deeper, we notice that the solvency capital requirement frontier generally avoids the available spread assets while the economic frontier seeks them, especially in lower risk solutions–typical trade-offs that ultimately come down to what is most important to the investor and where improvements become marginal.

Case 12:

Portfolio analysis with regulatory considerations
US Risk-Based Capital (RBC) National Association of Insurance Commissioners (NAIC)

Demonstrates how Invesco Vision clarifies the trade-off between the RBC frontier, which often leads to undesirably concentrated portfolios, and the economic risk frontier, which provides more diversification–and how Invesco Vision facilitates the construction of an insurance portfolio that falls ideally between the two. (See Figure C12a, Portfolio construction with regulatory considerations–Risk-based capital (RBC), and Figure C12b, Hybrid RBC/Economic risk portfolio on page 13.)

Case 13:

Model portfolio analytics
Evaluating target-date funds

Showcases how Invesco Vision reveals some key pitfalls in these solutions and its practical ability to compare different portfolios. Longer horizon portfolios often entail increasing levels of risk with only marginal expected return benefits. The transparency afforded by Invesco Vision can help provide valuable insights regarding how target-date funds are expected to behave.

Case 14:

Return agnostic solutions
Portfolio construction without expected returns

Highlights a number of approaches that are not dependent on expected returns, which are the hardest optimization inputs to correctly forecast. These solutions can be especially useful when there is low confidence in the ability to effectively forecast expected returns. They can also be a useful comparison reference for portfolios under consideration.

Case 15:

Multi-period optimization
Creating portfolios to meet multi-period goals

Invesco Vision's goal planning module allows users to create multi-period solutions, including time-varying allocations. This is particularly important for situations with expected inflows or outflows. Invesco Vision provides a graphical representation of the likelihood of the portfolio's value as a function of time and provides intuition on the evolutionary nature of the investment solution.

Figure C9a: Historical scenarios
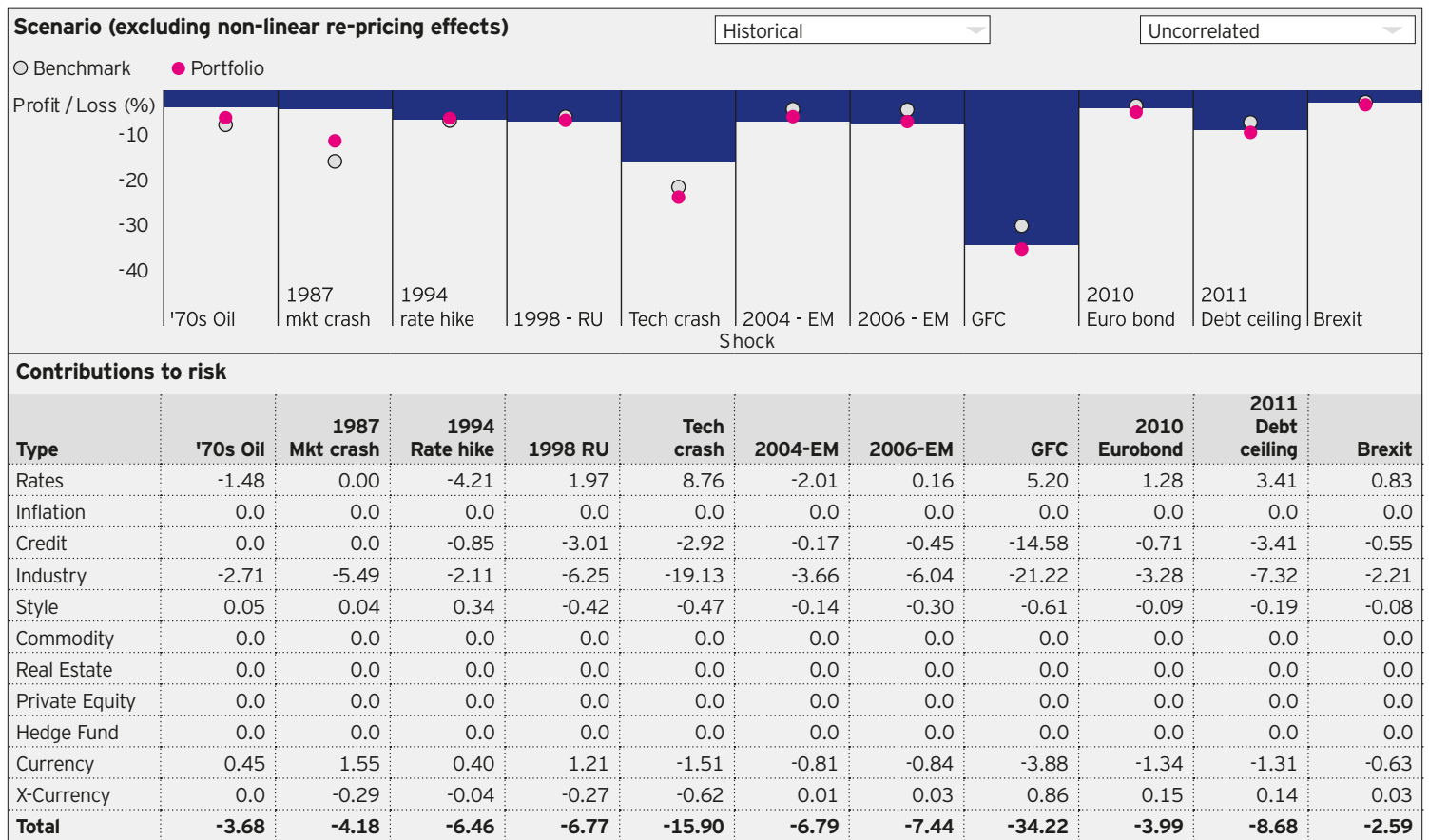Assuming uncorrelated sensitivities

Scenario (excluding non-linear re-pricing effects) | Historical ▾ | Uncorrelated ▾

○ Benchmark ● Portfolio

Profit / Loss (%)

Shock: '70s Oil | 1987 mkt crash | 1994 rate hike | 1998 - RU | Tech crash | 2004 - EM | 2006 - EM | GFC | 2010 Euro bond | 2011 Debt ceiling | Brexit

Contributions to risk

Type	'70s Oil	1987 Mkt crash	1994 Rate hike	1998 RU	Tech crash	2004-EM	2006-EM	GFC	2010 Eurobond	2011 Debt ceiling	Brexit
Rates	-1.48	0.00	-4.21	1.97	8.76	-2.01	0.16	5.20	1.28	3.41	0.83
Inflation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Credit	0.0	0.0	-0.85	-3.01	-2.92	-0.17	-0.45	-14.58	-0.71	-3.41	-0.55
Industry	-2.71	-5.49	-2.11	-6.25	-19.13	-3.66	-6.04	-21.22	-3.28	-7.32	-2.21
Style	0.05	0.04	0.34	-0.42	-0.47	-0.14	-0.30	-0.61	-0.09	-0.19	-0.08
Commodity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Real Estate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Private Equity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hedge Fund	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Currency	0.45	1.55	0.40	1.21	-1.51	-0.81	-0.84	-3.88	-1.34	-1.31	-0.63
X-Currency	0.0	-0.29	-0.04	-0.27	-0.62	0.01	0.03	0.86	0.15	0.14	0.03
Total	**-3.68**	**-4.18**	**-6.46**	**-6.77**	**-15.90**	**-6.79**	**-7.44**	**-34.22**	**-3.99**	**-8.68**	**-2.59**

Figure C9b: Hypothetical scenarios
Assuming correlated sensitivities

Scenario (excluding non-linear re-pricing effects) | Hypothetical ▾ | Correlated ▾

○ Benchmark ● Portfolio

Profit / Loss (%)

Shock: World -15% | US -15% | EAFE -15% | EM -15% | US Treasury +100 bps | US Treasury -100 bps | EUR/USD -15% | GBP/USD -15% | JPY/USD -15% | Oil -15% | Gold -15%

Contributions to risk

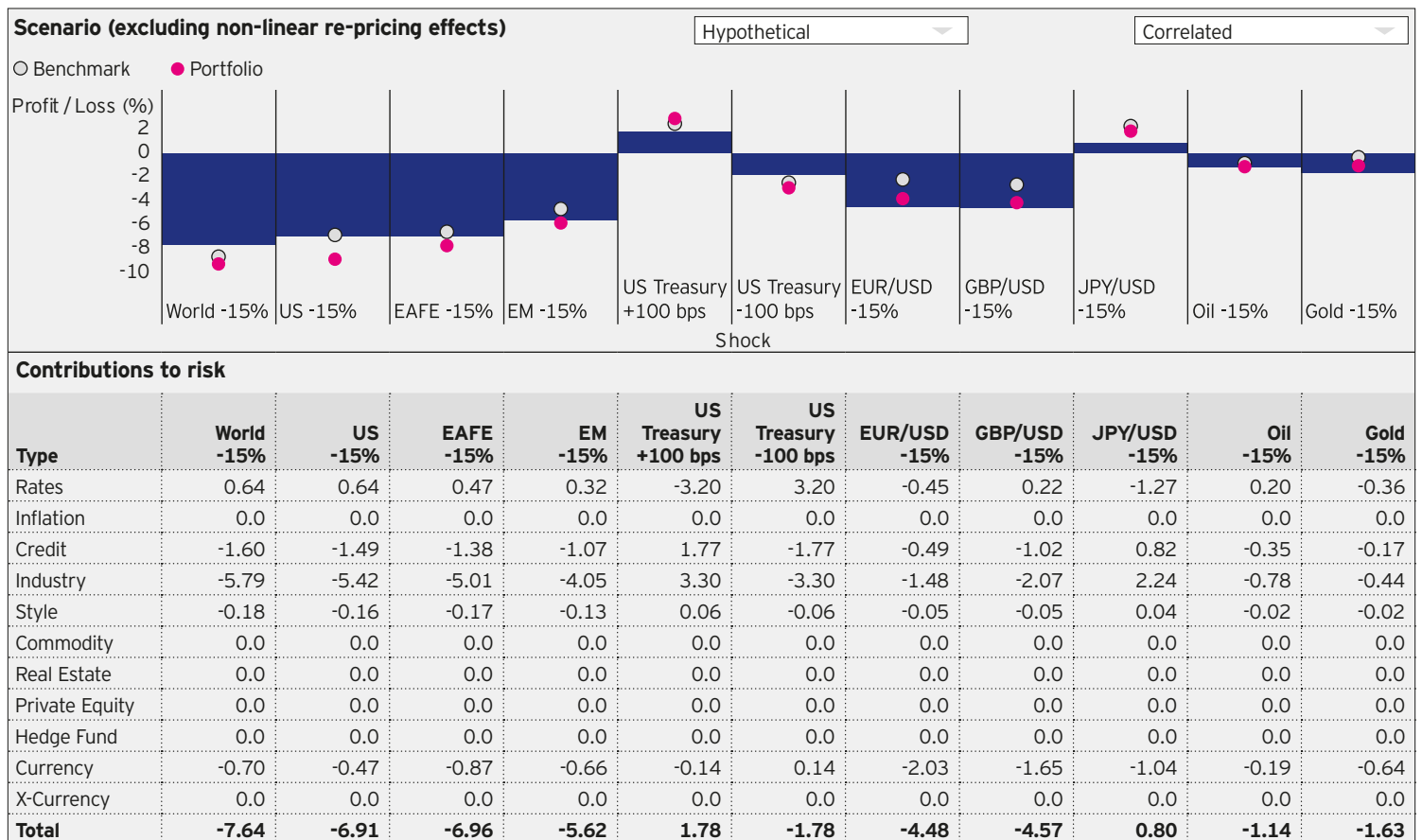| Type	World -15%	US -15%	EAFE -15%	EM -15%	US Treasury +100 bps	US Treasury -100 bps	EUR/USD -15%	GBP/USD -15%	JPY/USD -15%	Oil -15%	Gold -15%
Rates	0.64	0.64	0.47	0.32	-3.20	3.20	-0.45	0.22	-1.27	0.20	-0.36
Inflation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Credit	-1.60	-1.49	-1.38	-1.07	1.77	-1.77	-0.49	-1.02	0.82	-0.35	-0.17
Industry	-5.79	-5.42	-5.01	-4.05	3.30	-3.30	-1.48	-2.07	2.24	-0.78	-0.44
Style	-0.18	-0.16	-0.17	-0.13	0.06	-0.06	-0.05	-0.05	0.04	-0.02	-0.02
Commodity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Real Estate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Private Equity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hedge Fund	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Currency	-0.70	-0.47	-0.87	-0.66	-0.14	0.14	-2.03	-1.65	-1.04	-0.19	-0.64
X-Currency	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**-7.64**	**-6.91**	**-6.96**	**-5.62**	**1.78**	**-1.78**	**-4.48**	**-4.57**	**0.80**	**-1.14**	**-1.63**

Figure C12a: Portfolio construction with regulatory considerations – Risk-based capital (RBC)
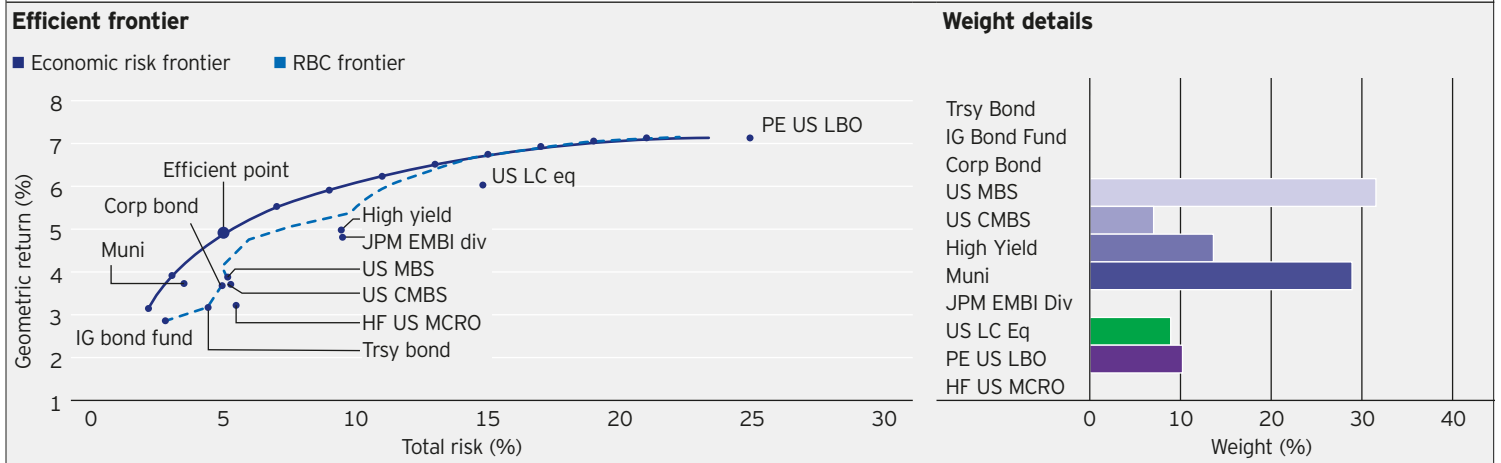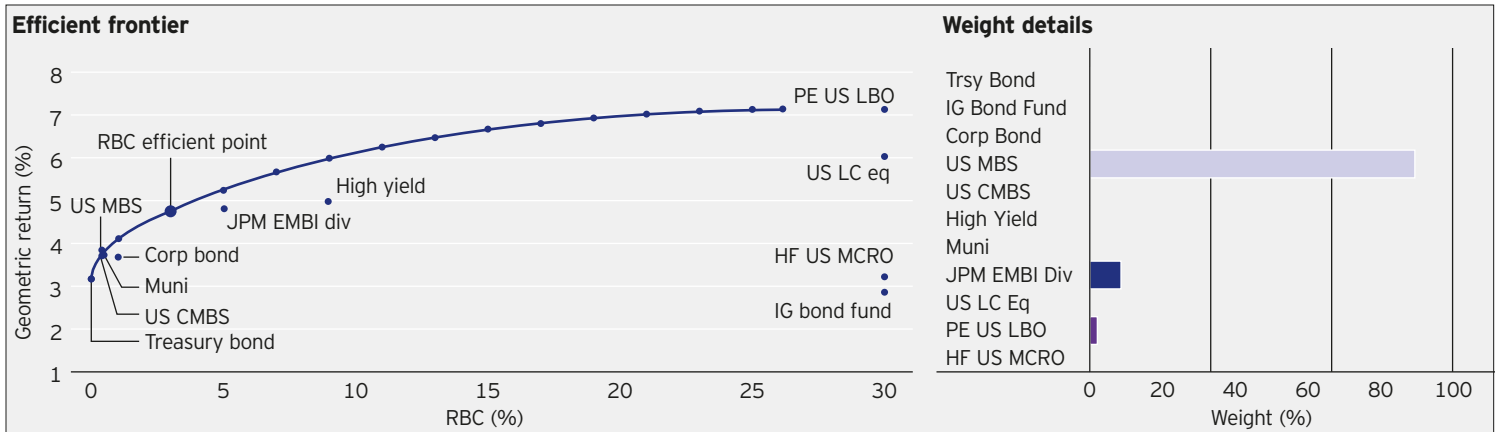Efficient frontiers based on RBC (top) and economic risk (bottom)

Efficient frontier

Weight details

Efficient frontier

- ■ Economic risk frontier ■ RBC frontier

Weight details

Figure C12b: Hybrid RBC/economic risk portfolio
RBC impact of fund-based versus direct investment – Investment grade bond

Efficient frontier

- ■ RBC frontier ■ Economic risk frontier

Weight details
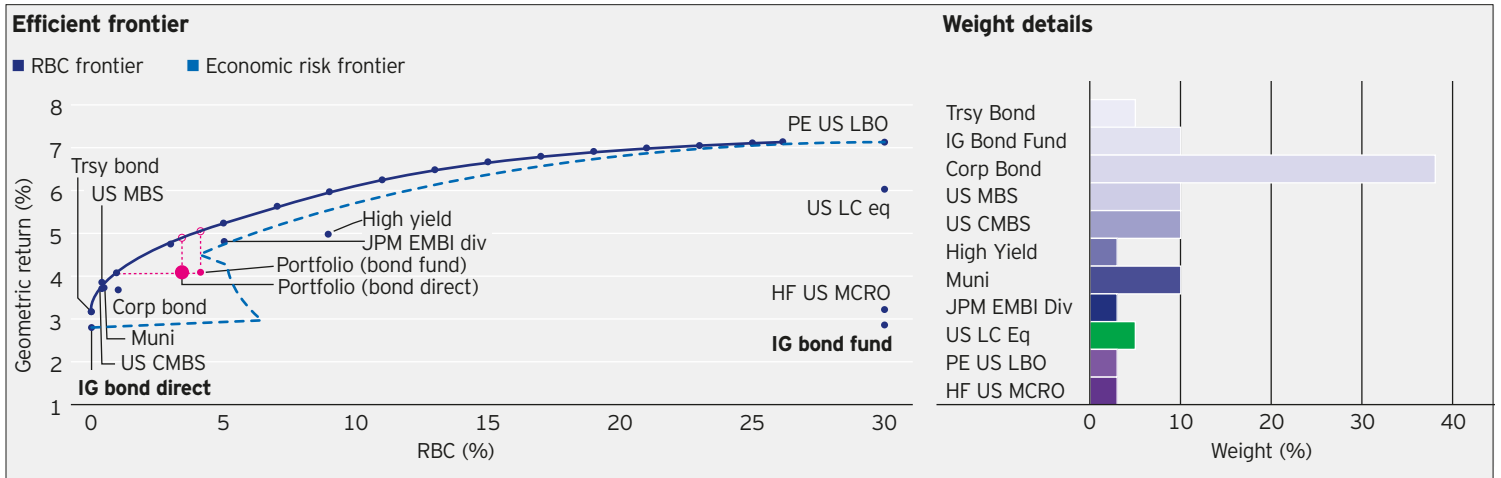
About Invesco

Invesco is a global, independent financial firm with a pure focus on investment management. Without competing pursuits, we aim to partner with clients to solve complex investment needs. With $954 billion in assets under management, and $335 billion of that devoted to institutional investing, we bring tremendous experience to crafting multifaceted, differentiated solutions for the most sophisticated institutional investors.[1]

1 Data as of March 31, 2019.

About Invesco Investment Solutions

Invesco Investment Solutions is an experienced multi-asset team that seeks to deliver purposeful outcomes using Invesco's global capabilities, scale and infrastructure. We partner with our clients to fully understand their goals and harness strategies across Invesco's global spectrum of active, passive, factor and alternative investments that address their unique needs. From robust research and analysis to bespoke investment solutions, our team brings insight and innovation to each client's portfolio construction process.

- We help support better investment outcomes by delivering insightful and thorough analytics.

- By putting analytics into practice, we develop investment approaches specific to each client's needs.

- We work as an extension of the client's team to engage across functions and implement solutions.

Assisting clients in North America, Europe and Asia, Invesco Investment Solutions consists of over 50 professionals, with 20+ average years of experience across the leadership team. The team benefits from Invesco's on-the-ground presence in more than 20 countries worldwide, with over 150 professionals to support investment selection and ongoing monitoring.

Contacts

Neil Blundell
Head of Global Client Solutions
+1 212 278 9174
neil.blundell@invesco.com

North America

Vincent de Martel, CFA
Senior Solutions Strategist
+1 650 316 6509
Vincent.deMartel@invesco.com

Chris Hamilton, CFA, CAIA
Senior Solutions Strategist
+1 713 214 1429
Christopher.Hamilton@invesco.com

EMEA

Mark Humphreys
Head of EMEA Client Solutions
+44 20 7543 3537
mark.humphreys@invesco.com

Alexandre Mincier
Head of Global Insurance Client Solutions
+33 (0) 1 56 62 43 06
Alexandre_Mincier@invesco.com

Charles Moussier
Head of EMEA Insurance Client Solutions
+33 (0) 1 56 62 43 05
Charles.Moussier@invesco.com

APAC

Shu Irikura
Head of Japan Client Solutions
+813 6447 3063
shu_irikura@tyo.invesco.com

Nixon Mak
Head of Hong Kong Pension & Solutions Strategist
+852 3128 6845
Nixon.Mak@invesco.com

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Russell SCG Cash Flow Generator.

Contributors

Investment Solutions Research and Portfolio Analytics

Yuan Gao
Quantitative Research Analyst

Anish Ghosh, FRM
Senior Quantitative Research Analyst

Steve Kusiak, PhD
Solutions Research Strategist

Peter Miller, CFA, FSA
Insurance Research Strategist

Harveen Oberoi
Quantitative Research Analyst

Nicholas Savoulides, PhD, CFA
Head of Solutions Research

Yifan Yang
Quantitative Research Analyst

Shin Zhao, CFA
Technical Business Partner

Qi Zheng
Quantitative Research Analyst

Vicky Zhou
Quantitative Research Analyst

Technology - Investment Engineering

Laxmikant Bhattad, CFA, FRM
Advanced Business Analyst

Satish Duvvuri
Manager

Julio Guzman, CFA, CIPM
Associate Director

Amir Hirani
Principal Business Analyst

Zhenyang Lu
Senior Engineer

Abinand Malve
Advanced Engineer

Alex Nocella, CFA, FRM, CAIA, CIPM
Senior Engineer

Debesh Sahay
Principal Engineer

Isha Sahu
Senior Engineer

Kandasamy Thangavelu, CFA
Principal Engineer

Sai Abhishek Vedula, FRM
Senior Engineer II

Investment Solutions Thought Leadership

Kenneth Blay
Head of Solutions
Thought Leadership

Investment risks

The value of investments and any income will fluctuate (this may partly be the result of exchange rate fluctuations) and investors may not get back the full amount invested.

   Diversification and asset allocation do not guarantee a profit or eliminate the risk of loss.

   Invesco Investment Solutions (IIS) develops Capital Market Assumptions (CMAs) that provide long-term estimates for the behavior of major asset classes globally. The team is dedicated to designing outcome-oriented, multi-asset portfolios that meet the specific goals of investors. The assumptions, which are based on 5- and 10-year investment time horizons, are intended to guide these strategic asset class allocations. For each selected asset class, IIS develop assumptions for estimated return, estimated standard deviation of return (volatility), and estimated correlation with other asset classes. Estimated returns are subject to uncertainty and error, and can be conditional on economic scenarios. In the event a particular scenario comes to pass, actual returns could be significantly higher or lower than these estimates.

   This information is not intended as a recommendation to invest in a specific asset class or strategy, or as a promise of future performance. Refer to the IIS CMA methodology paper for more details.