Executive Summary

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.
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.)

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)

**Efficient frontier**
- Frontier
- Frontier with alternatives

**Factor analysis**
- Benchmark
- Portfolio
- Rates
- Inflation
- Credit
- Equity
- Commodity
- Real Estate
- Private
- Hedge Fund
- Specific Risk
- Currency
- Total

**Frontier weights**
- Agg Bond
- Corp Bond
- High Yield
- US LC Eq
- Dev xUS Eq
- Em Mkt Eq
- RE US Mez
- RE US Core
- PE US SBO
- IFRE US Ren

**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.
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.
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.

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**Figure C5b: Liability-driven investing – US corporate defined benefit plan**

Liability relative efficient frontier

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<td>Specific Risk</td>
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<th>Frontier weights</th>
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<td>Assets - other</td>
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Cash flows

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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.

<table>
<thead>
<tr>
<th>Case 1:</th>
<th>Absolute risk optimization Creating an efficient frontier</th>
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<tbody>
<tr>
<td></td>
<td>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.</td>
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<th>Case 2:</th>
<th>Relative risk optimization Creating a style-premia portfolio</th>
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<tr>
<td></td>
<td>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.</td>
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<th>Case 3:</th>
<th>Relative risk optimization Optimizing with a reference portfolio</th>
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<td></td>
<td>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.</td>
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<th>Case 4:</th>
<th>Robust optimization Addressing estimation error in portfolio construction</th>
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<td>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.</td>
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<th>Case 5:</th>
<th>Liability-driven investing LDI solutions for US corporate defined benefit plans</th>
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<td>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.</td>
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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.
<table>
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<th>Case 11:</th>
<th>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.</th>
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<td>Case 12:</td>
<td>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.)</td>
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<td>Case 13:</td>
<td>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.</td>
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<td>Case 14:</td>
<td>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.</td>
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<tr>
<td>Case 15:</td>
<td>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.</td>
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**Figure C9a: Historical scenarios**
Assuming uncorrelated sensitivities

**Scenario (excluding non-linear re-pricing effects)**

<table>
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<tr>
<th>Profit / Loss (%)</th>
<th>Historical</th>
<th>Uncorrelated</th>
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<td>Portfolio</td>
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<td>1970s Oil</td>
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<td>Brexit</td>
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**Contributions to risk**

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**Figure C9b: Hypothetical scenarios**
Assuming correlated sensitivities

**Scenario (excluding non-linear re-pricing effects)**

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<th>Profit / Loss (%)</th>
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<td>Tech crash</td>
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<td>2004 - EM</td>
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<td>2006 - EM</td>
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<td>GFC</td>
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<tr>
<td>2010 Euro bond</td>
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<td>2011 Debt ceiling</td>
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**Contributions to risk**

<table>
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<tr>
<th>Type</th>
<th>World</th>
<th>US</th>
<th>EAFE</th>
<th>EM</th>
<th>US Treasury +100 bps</th>
<th>US Treasury -100 bps</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
<th>JPY/USD</th>
<th>Oil</th>
<th>Gold</th>
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<tr>
<td><strong>Rates</strong></td>
<td>0.64</td>
<td>0.64</td>
<td>0.47</td>
<td>0.32</td>
<td>-3.20</td>
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<td><strong>Inflation</strong></td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td><strong>Credit</strong></td>
<td>-1.60</td>
<td>-1.49</td>
<td>-1.38</td>
<td>-1.07</td>
<td>1.77</td>
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<td>-1.02</td>
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<td>-5.01</td>
<td>-4.05</td>
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<td>0.00</td>
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<td><strong>Private Equity</strong></td>
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<tr>
<td><strong>Hedge Fund</strong></td>
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<tr>
<td><strong>Currency</strong></td>
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<td>-0.66</td>
<td>-0.14</td>
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<tr>
<td><strong>Total</strong></td>
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<td>-6.91</td>
<td>-6.96</td>
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<td>-4.57</td>
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</table>
**Figure C12a: Portfolio construction with regulatory considerations - Risk-based capital (RBC)**

Efficient frontiers based on RBC (top) and economic risk (bottom)

**Efficient frontier**

- **RBC frontier**
- **Economic risk frontier**

**Weight details**

<table>
<thead>
<tr>
<th>Portfolio (bond fund)</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>Trsy Bond</td>
<td>0</td>
</tr>
<tr>
<td>IG Bond Fund</td>
<td>20</td>
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<tr>
<td>Corp Bond</td>
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<tr>
<td>US MBS</td>
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</tr>
<tr>
<td>US LC eq</td>
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</tr>
<tr>
<td>US CMBS</td>
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</tr>
<tr>
<td>High Yield</td>
<td>15</td>
</tr>
<tr>
<td>Muni</td>
<td>20</td>
</tr>
<tr>
<td>JPM EMBI Div</td>
<td>25</td>
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<tr>
<td>US LC Eq</td>
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<tr>
<td>PE US LBO</td>
<td>0</td>
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<tr>
<td>HF US MCRO</td>
<td>0</td>
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</tbody>
</table>

**Efficient frontier**

- **RBC frontier**
- **Economic risk frontier**

**Weight details**

<table>
<thead>
<tr>
<th>Portfolio (bond direct)</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>Trsy Bond</td>
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<td>HF US MCRO</td>
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</tbody>
</table>

**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**

<table>
<thead>
<tr>
<th>Portfolio (bond fund)</th>
<th>Weight (%)</th>
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<tr>
<td>Trsy Bond</td>
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<td>HF US MCRO</td>
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**Efficient frontier**

- **RBC frontier**
- **Economic risk frontier**

**Weight details**

<table>
<thead>
<tr>
<th>Portfolio (bond direct)</th>
<th>Weight (%)</th>
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<tbody>
<tr>
<td>Trsy Bond</td>
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<td>HF US MCRO</td>
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</table>
See It in Practice

For a demonstration of Invesco Vision, or to download our comprehensive white paper, “Invesco Vision: Portfolio Management Decision Support System,” please search for Invesco Vision on your local Invesco website or contact your Invesco relationship manager.

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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.
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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.

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Thought Leadership
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- does not address local tax issues.

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