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BlackRock®

Augmented Investment Management

A systematic framework for designing alpha models



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Summary

- **The challenge:** In our data-rich world, active investment managers face an increasing challenge of distilling a wide range of information sources into a holistic investment view. For systematic investors, the growing number of predictive investment signals requires a novel solution for combining these insights into alpha models that can be used in portfolios.

- **Our approach:** Advances in machine learning offer powerful tools to address the challenge of signal combination. This led BlackRock's Systematic Investment Team to develop a system for designing alpha models called Augmented Investment Management ("AIM").

- **Our framework:** AIM brings customization, scalability, and transparency to the process of building alpha models. At the core of AIM is a modular machine learning pipeline that can be configured and fine-tuned by portfolio managers for specific purposes — bringing together human expertise and proprietary technology to enhance active management capabilities.

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The challenge

Successful active management as we see it relies on the premise that investors can gain an informational advantage over other market participants to generate excess returns. Today's investors, regardless of approach, are synthesizing a growing volume of data and information to form their investment views. Fundamental managers tend to employ intuition and judgment to distill this information into a set of investment decisions. In contrast, systematic investors codify information sources into predictive investment signals that serve as building blocks in an investment strategy.

Systematic investment signals offer the opportunity to uncover potentially valuable patterns and relationships in financial markets. Insights gleaned from a wider breadth of data can offer a level of analysis simply not possible for an individual or even a team of individuals to compute on their own. Signals can be designed to analyze traditional financial indicators, like enterprise value-to-sales ("EV/sales"), a measure of a company's total value. A low EV/sales value may suggest that the security is priced attractively relative to the firm's future revenues. Signals can also be constructed to capture non-traditional measures of companies, such as company sentiment. For example, applying text analysis algorithms to analyst reports can provide better insight into whether analysts have positive or negative views of the firm. Alternative measures of corporate value can also be captured by signals, such as the number of web searches for a specific company's products. This signal can help to evaluate consumer interest and potentially forecast future sales.

These are just a few examples of the signals developed within BlackRock's Systematic Investment Team over more than 40 years of alpha research and innovation.[1] In an increasingly data-rich world, there are now potentially hundreds or even thousands of signals available to investors. This raises a new challenge for systematic investors, which is how to optimally combine investment signals. Traditionally, signal combination has been solved through a discretionary approach where portfolio managers assign weights to a subset of signals to form an alpha model.

In making these allocation decisions, managers have to account for a multitude of complexities:

- **Signals derived from different data sources can be correlated.** For example, a signal derived from price-to-earnings ratios may be correlated with another signal based on price-to-sales ratios. Ignoring the correlation between these signals could lead to overexposure to a particular market factor or risk.

- **The predictive value of signals often varies across sectors or regions.** For example, traditional valuation measures are less relevant for biotech firms, many of which report little or no revenues.

- **The predictive power of signals can vary over different investment horizons.** A signal based on recent price moves might have forecasting power over the next few days, whereas a signal derived from fundamental measures of firm performance may have greater predictive power over the next few months. Investment managers may want to consider a mix of signals that is tailored to the capacity of the fund and associated trading frictions in the market it operates in.

- **The predictive power of signals can decay over time.** As market environments change or information gets priced into markets, the ability of investment signals to harness alpha opportunities can diminish. A systematic approach requires continuous innovation.

These complexities, coupled with the growing arsenal of signals available, make building alpha models using a purely discretionary approach a formidable task. These considerations motivated our Systematic Investment Team to search for algorithmic solutions to this problem.

1 Note: 40-year history includes predecessor firms.

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Our approach

Advances in machine learning offer powerful tools to help address the challenges faced by investment managers in designing alpha models. Machine learning algorithms, such as decision trees or deep neural networks, have demonstrated remarkable capabilities in extracting patterns and relationships from complex, large-scale data sets.[2,3] For this reason, machine learning tools offer a dynamic alternative to designing alpha models through a discretionary approach.

Rather than viewing the challenge of combining signals as a weight allocation problem, we reframe it as a forecasting problem. This approach requires combining signals into a forecast of excess returns, which we call *alpha forecasts* for each asset in the investible universe. These alpha forecasts are fed to a portfolio optimizer that accounts for co-movement of securities, transaction costs, and various portfolio constraints seeking to generate optimal holdings and associated trades. This separation between alpha forecasting and risk-aware portfolio construction is a common approach in systematic investing, leading to a more tractable problem formulation and a more readily interpretable solution.

Starting in 2014, we set out to design a system that can train machine learning models for this purpose. We named the system Augmented Investment Management ("AIM"), drawing an analogy to augmented reality devices that enhance human decision-making by overlaying additional information and insights. AIM is a system for building systematic alpha models from a large collection of signals.

Its core design is guided by the following characteristics:

Systematic. AIM uses machine learning techniques to generate alpha forecasts from a large collection of signals. Portfolio managers assign a user-specified objective function that the model can be designed to solve. Based on the objective function, AIM automatically identifies relevant signal data, applies a series of processing steps, trains the model to forecast alpha, and tunes the model parameters that are learned from historical data which seeks to maximize model performance.

Customizable. AIM models are modular. They consist of several components that are chained together to create a machine learning pipeline, which can be configured using a configuration file to adjust the model. Portfolio managers can customize AIM models by adding or removing components from the pipeline, modifying the parameters, and tailoring the objective function to target a desired outcome based on the investment objective.

Scalable. Combining the first two principles of being systematic and customizable, AIM facilitates scalable model building. For example, portfolio managers have the ability to use the same set of signals to produce different investment models for a series of strategies with different risk and return mandates without having to manually build and manage separate models. To train models at scale, the underlying infrastructure makes frequent use of distributed computing resources.

Transparent. To improve the transparency of machine learning models, AIM offers an explanation model to provide an interpretable view of the contribution of each signal to model prediction. These analytics can be useful during model development as a diagnosis tool, as well as for live monitoring during trading.

2 Hastie, T., Tibshirani, R., & Friedman, J. (2009). The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Springer Series in Statistics. **3** Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep Learning. MIT Press.

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Our framework

AIM relies on two key ingredients. The first is a comprehensive signal library with substantial historical data available for model training. BlackRock's systematic signal library has been built upon 40 years[4] of alpha research. The library includes a wide range of signals from different sources, including financial statements, market indicators, news and analyst reports, and an array of alternative data sources. We devote considerable resources to maintaining accurate point-in-time historical data, employ various data preprocessing techniques to clean and normalize the data, and associate it with assets in our investible universe. Figure 1 illustrates the growth in the number of stock-selection signals developed by our team over the past decade.

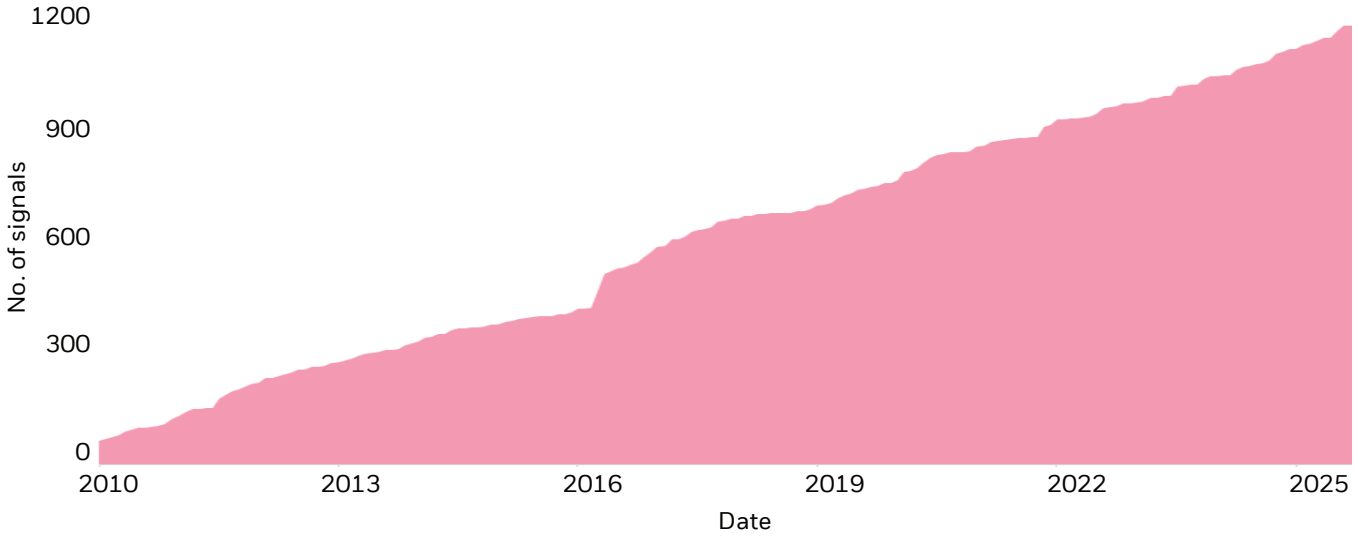
The second ingredient is a high-fidelity, high-performance portfolio optimizer and performance simulator. The portfolio optimizer is used to transform forecasts into portfolio positions by solving a constrained optimization problem accounting for portfolio risk. The performance simulator is then used to evaluate portfolio holdings over a historical backtest period, and model parameters are adjusted with the aim of maximizing a specific performance metric, e.g., the Information Ratio (IR) of the portfolio. The simulator accounts for transaction costs, borrow costs, and fund constraints to produce evaluation results that approximate realized portfolio performance with high fidelity.[5]

At its core, AIM is designed as a modular machine learning pipeline that can be configured and customized by portfolio managers. Figure 2 (on the following page) illustrates the key components in the pipeline used to process raw signal data, train a machine learning model, and evaluate the model's performance.

In the initial step, raw signal data is processed to form a feature matrix.[6] This step involves handling outliers, imputing missing values, applying time-series transformations, and (optionally) seeking to neutralize the effect of risk factors. The feature matrix is coupled with a target variable, which represents the measure that we're trying to predict and is typically generated based on forward- looking returns over a specified time horizon. The feature matrix and target variable are constructed over a long historical period, typically in the range of 10 to 20 years, and used as training data in the next step.

Next, a model is initialized according to the configuration supplied by the portfolio manager and fits to the training data constructed in the previous step. The choice of

Figure 1: The number of stock selection signals in BlackRock's systematic signal library continues to grow over time



Source: BlackRock Systematic, as of September 30, 2025.

4 Note: 40-year history includes predecessor firms. **5** The back-testing done by the performance simulator is described for illustrative purposes only and is not meant to be representative of any account, portfolio or strategy. No representation is being made that any account, portfolio or strategy will or is likely to achieve certain results based on the back test. There is no guarantee that any forecasts will come to pass. **6** In the machine learning literature, independent variables used as predictions are referred to as features. We adopt this terminology throughout this work.

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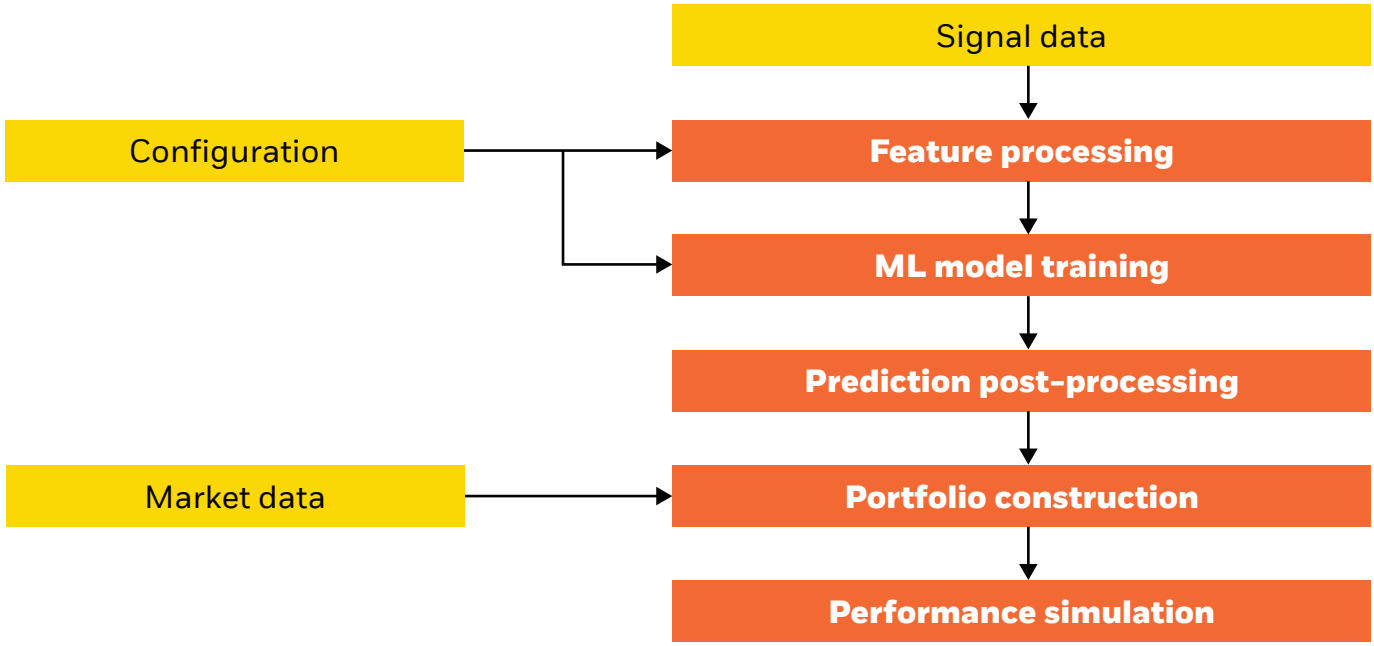
machine learning model and its parameters is guided by a large-scale search over possible configurations. AIM supports a variety of machine learning models, including regularized linear models, gradient boosting ensembles, neural network architectures, and proprietary variants. The machine learning model uses the available historical data to identify associations between input features (signals) and the target variable (excess returns). For linear models, this involves assigning higher weights to signals that have historically demonstrated positive predictive power. More complex models like neutral networks learn a non-linear transformation of the input features that can best predict the target variable. Although these more complex models can facilitate a better understanding of data relationships, they also increase the likelihood of overfitting. Overfitting is a common pitfall in machine learning, where a model is excessively tuned to the training data, diminishing its predictive performance on new, unseen data.

To mitigate the risks of overfitting, AIM incorporates stringent validation protocols, relying on cross-validation. In detail, the dataset is partitioned into subsets, and the model is trained on a portion of the data — called the training set — and then tested on the remaining 'held-out' data to validate its performance. This process can be repeated multiple times, rotating the data used for training and validation. The advantage of cross-validation is that it provides a more reliable estimate of the model's ability to generalize to new data by evaluating its performance on data that the model has not seen during training.

During validation, it is important to calculate historical performance measures using a realistic portfolio simulation that accounts for market frictions. To that end, model predictions are post-processed into alpha forecasts, and fed to a portfolio optimizer. The optimizer is responsible for transforming the alpha forecasts into portfolio holdings — accounting for fund specifications, estimated transaction costs, and portfolio constraints. This ensures that the portfolio is optimized in line with the investor's goals and risk tolerance, while also considering market dynamics and potential costs associated with trading. In the final component of the AIM pipeline, portfolio performance is evaluated over a historical period, using a realistic simulation environment. The portfolio simulator produces an array of performance measures that are used to evaluate the performance of the machine learning model over the validation period and tune the pipeline configuration.

In summary, AIM allows portfolio managers to create models that are sophisticated enough to capture complex signal interactions yet general enough to seek to perform well on unseen data, balancing model capacity with versatility.

Figure 2: The machine learning pipeline used in AIM



Source: BlackRock Systematic, as of September 30, 2025. Model construction process provided for illustrative purposes only and is subject to change without notice.

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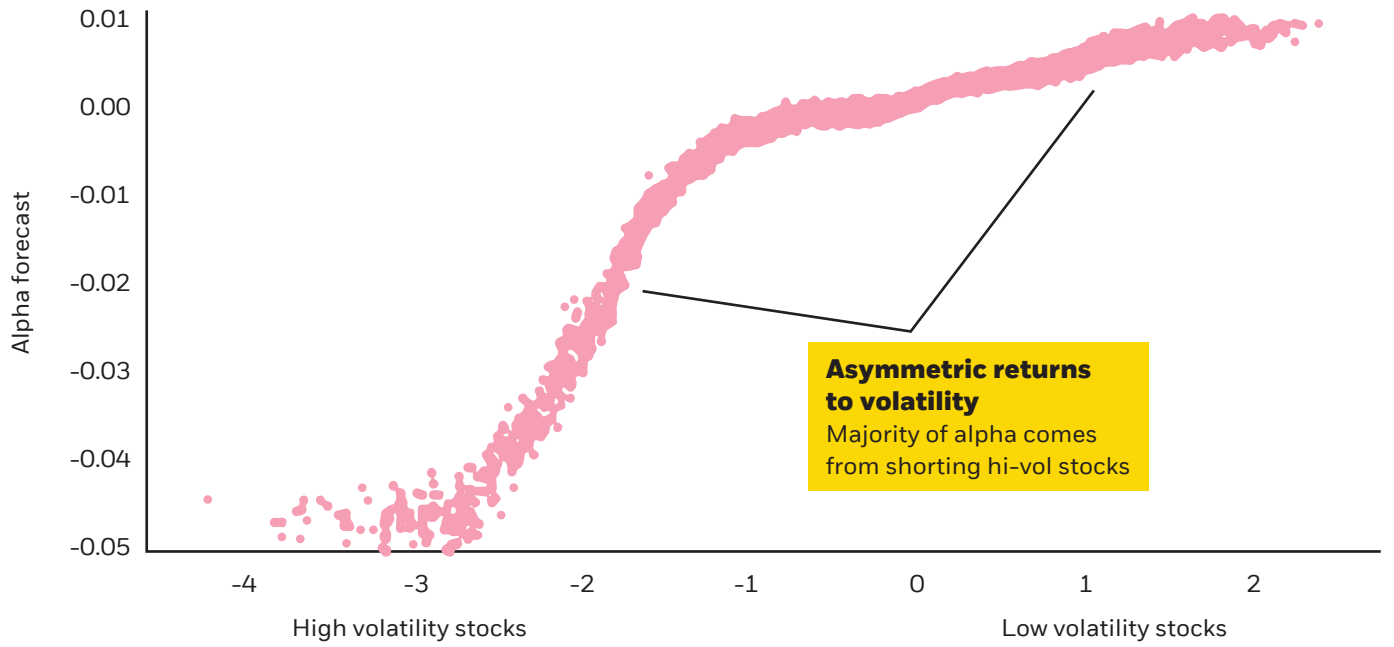
Looking under the hood

The machine learning pipeline described on the previous page involves non-linear transformations of the input signals, making it difficult to link model predictions with corresponding input signals. Model interpretability is important not only for performance attribution, but also to guide model development (diagnosing data issues, identifying appropriate feature transformations, etc.). To solve for this challenge, machine learning researchers often turn to explanation models, which are interpretable approximations of the original model. In AIM, we have adopted an additive attribution approach based on Shapley regressions,[7] which produces a decomposition of the prediction value into a sum of individual signal contributions.

Figure 3 illustrates the model's view of one signal in the library that measures stock-specific volatility. The horizontal axis of the scatter plot corresponds to signal values, representing the level of stock volatility. The vertical axis shows the corresponding contribution to the alpha forecast, i.e., how much of the overall model forecast is attributed to this signal value. Individual points on the graph represent assets in the investible universe of about 3,000 large and mid-cap stocks in developed market countries. If we were to fit a linear model, the points in the graph would lie on a straight line, i.e., the contribution of the signal would be linearly proportional to the value of the signal for each asset. However, as evident in the figure, the model discovers a non-linear, asymmetric relationship between volatility and stock returns. This model discovery is consistent with evidence in the economic literature, namely that the empirical relationship between historical volatility and expected returns is negative.[8,9]

Figure 3: The model discovers an asymmetric relationship between volatility and stock returns
Model view of stock-specific volatility



Source: BlackRock Systematic, as of June 2023. Constructed using proprietary signal construction methodology over the MSCI ACWI small-cap universe. **The figures shown relate to past performance. Past performance is not a reliable indicator of current or future results.** Forecasts of financial market trends that are based on current market conditions constitute our judgment and are subject to change without notice. For illustrative purposes only.

7 Lundberg, S. M., & Lee, S. I. (2017), A unified approach to interpreting model predictions, *Advances in neural information processing systems, 30.* **8** Van Vliet, Blitz, van der Grient, Is the Relation between Volatility and Expected Stock Returns Positive, Flat or Negative? **9** Ang, Hodrick, Xing, Zhang, The Cross-Section of Volatility and Expected Returns.

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Customizing alpha models

Predicting inflection points in global financial markets or the outcomes of macroeconomic shocks is a very difficult task, and portfolio managers are often guided by judgement and intuition when assessing regime changes and repositioning portfolios. By combining this human expertise with machine learning, we can enhance our approach for preparing for shifts in market regimes. A key benefit of machine learning systems is the low marginal cost of designing custom alpha models. Thus, portfolio managers can use AIM to design regime-aware models that are trained to be more resilient during negative regimes. This approach is analogous to earthquake management, where, due to the lack of reliable earthquake forecasting models, earthquake-resilient structures and contingency plans are developed to handle seismic events.

A simple and intuitive approach to training resilient models is to overstate the likelihood of negative regimes in the historical data used to train the model. This is akin to training the model on an alternate history where the prevalence of negative states (e.g., bear markets) is significantly higher. As a result, the model learns that to do well on its training data, it needs to find investment patterns that perform well during negative regimes.

Besides facilitating customization, these methods also help to safeguard against the pitfall of over-reliance on a dominant market regime in the training data. Through a training regime that emphasizes a higher frequency of negative states, the model explores diverse investment patterns for robust performance across market variations. This technique insulates AIM models against over-fitting to a particular market regime, leading to more stable and resilient portfolio strategies.

As a concrete example, we used AIM to train an alpha model that is more resilient to drawdowns of a broad equity index, in this case the MSCI World index. Starting with index returns, we resampled periods where the index return was consistently negative to overstate the likelihood of drawdowns, and trained a model on resampled historical data. Figure 4 (on the following page) summarizes the hypothetical historical performance of this defensive model relative to a baseline model trained on the same historical data without resampling. We find that the defensive model picks up many of the characteristics that we would expect a defensive strategy to have, including better risk-adjusted performance during market drawdowns relative to the benchmark, and lower overall drawdowns, particularly around periods of market stress like the Great Financial Crisis (“GFC”). This more resilient performance comes at a cost. Compared with the baseline model, the defensive model incurs a 20% performance haircut overall. We further found that the model intuitively discovers investment patterns that are consistent with a defensive strategy, by avoiding leveraged, high growth, high volatility names, and realizing an overall negative exposure to these risk factors (Figure 5, on the following page).



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Figure 4: The defensive model demonstrates better risk-adjusted performance during historical drawdowns, but weaker performance than the baseline model overall

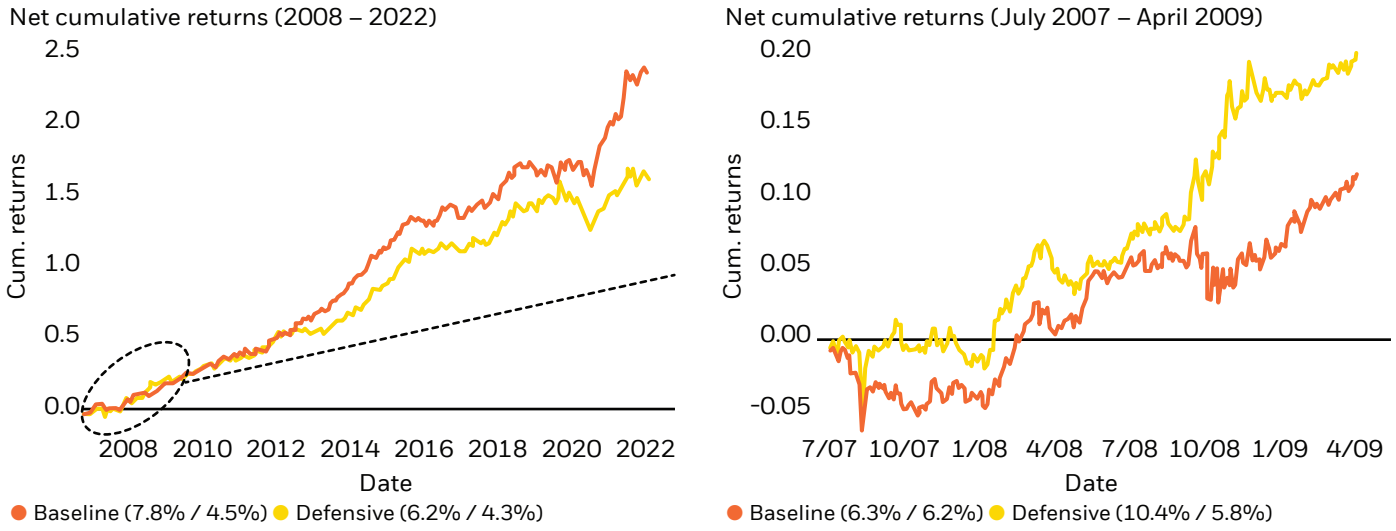
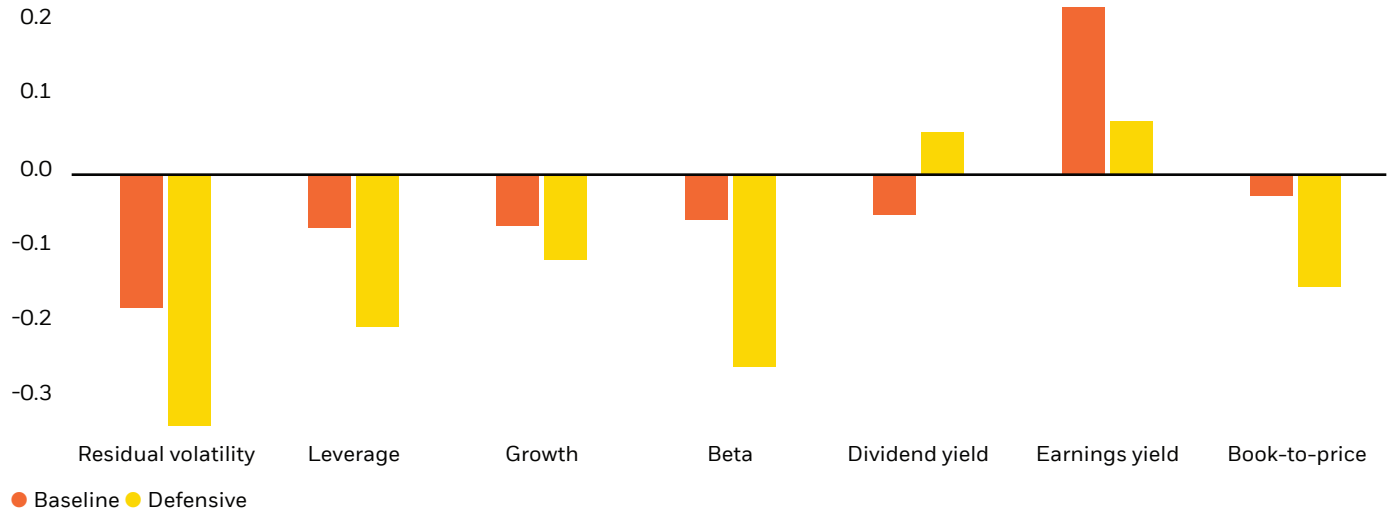


Figure 5: The defensive model reflects investment patterns that are consistent with expectations of a defensive strategy

Baseline and defensive model risk exposures



Capital at risk. The figures shown relate to past performance. Past performance is not a reliable indicator of current or future results. Index performance returns do not reflect any management fees, transaction costs or expenses. Indices are unmanaged and one cannot invest directly in an index.

Source (Figure 4 and Figure 5): BlackRock Systematic, as of June 2023. The model is shown for informational purposes only. It is not meant to be a prediction or projection of the defensive model. It is provided to illustrate the characteristics and historical performance of the defensive alpha model through different market regimes. Actual returns may vary. The model is based purely on assumptions using available data, based on past and current market conditions, and assumptions relating to available investment opportunities, each of which are subject to change. The underlying assumptions in the model do not include all assumptions that may have been applied to a particular model, and the model itself does not factor in every performance factor that can have a significant impact on the performance of the defensive model. Since many potential scenarios exist, it is impossible to show all of the potential circumstances that could yield similar results. Actual events will vary and may differ materially from those assumed. The model is subject to significant limitations. It cannot account for the impact that economic, market, and other factors may have on the implementation of an actual investment. In addition to the variables identified above, the return of any portfolio will vary materially from the returns shown based on numerous factors. The model's simulated performance also has inherent limitations. Back-tested performance is used for illustrative purposes only and is not meant to be representative of any account, portfolio or strategy. There is no guarantee that any forecasts will come to pass. Results do not represent actual trading, and thus do not reflect transaction costs. The results may not reflect material economic and market factors. No representation is made that a client account will achieve results similar to those shown, and performance of actual client accounts may vary significantly from the hypothetical or back- tested results.

Putting it all together

AIM seeks to allow portfolio managers to harness the power of machine learning to design alpha models. Managers can use their expertise to calibrate, customize, and scale alpha models — relying on AIM to automate the complex task of optimally combining and considering non-linear relationships across a large set of individual signals.

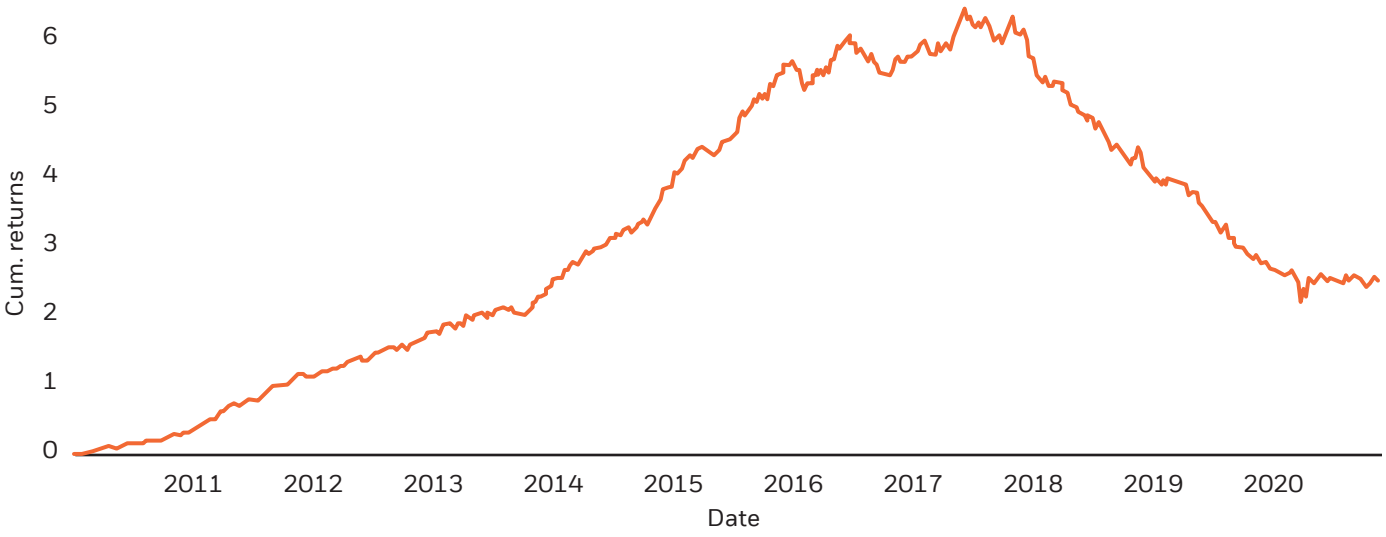
Portfolio managers configure the component pieces of AIM models to fit a specific function or investment mandate using their domain knowledge and historical training data. In the context of the previous example, a defensive alpha model may be used in a strategy with a conservative risk allocation or to limit portfolio drawdowns during periods of market stress. Portfolio managers can tailor models to capture opportunities as they arise, for example to target returns that aren't explained by traditional risk factors. The combination of human expertise and machine learning is what we believe makes AIM such a powerful tool for constructing systematic portfolios while balancing risk and return considerations.

Ongoing research directions

A fundamental assumption common to most machine learning models is that data used for training the model is drawn from the same distribution as live data used for inference. When the two distributions diverge, a phenomenon referred to as non-stationarity or covariate shift, the ability of a machine learning model to generalize from training data to live data is hampered. Non-stationarity is common in financial data and manifests in different forms.

First, signals can lose efficacy over time as sources of data become commoditized or underlying mechanisms become well understood by market participants. Figure 6 illustrates the cumulative returns of a calendar seasonality signal over the past decade, demonstrating a sharp turning point in the predictive ability of the signal. This is a particularly acute example of a change in the predictive power of a signal. More often, signals tend to stagnate or flatline and their predictive power decays over time.

Figure 6: Historical returns of a seasonality signal



Source: BlackRock Systematic, as of November 2020. **The figures shown relate to past performance. Past performance is not a reliable indicator of current or future results.** The model is shown for informational purposes only. It is not meant to represent actual returns of, or to be a prediction or projection, of the signal. It is provided to illustrate the cumulative returns of a calendar seasonality signal over the past decade. Actual returns may vary. The model is based purely on assumptions using available data, based on past and current market conditions, and assumptions relating to available investment opportunities, each of which are subject to change. The underlying assumptions in the model do not include all assumptions that may have been applied to a particular model, and the model itself does not factor in every performance factor that can have a significant impact on the signal. Since many potential scenarios exist, it is impossible to show all of the potential circumstances that could yield similar results. Actual events will vary and may differ materially from those assumed. The model is subject to significant limitations. It cannot account for the impact that economic, market, and other factors may have on the implementation of an actual investment. In addition to the variables identified above, the return of any portfolio will vary materially from the return shown based on numerous factors. The model's simulated performance also has inherent limitations. The results do not represent actual trading, and thus do not reflect transaction costs. Returns may not reflect material economic and market factors. No representation is made that a client account will achieve results similar to those shown, and performance of actual client accounts may vary significantly from the hypothetical results due to the customization of advice to each client and other factors.

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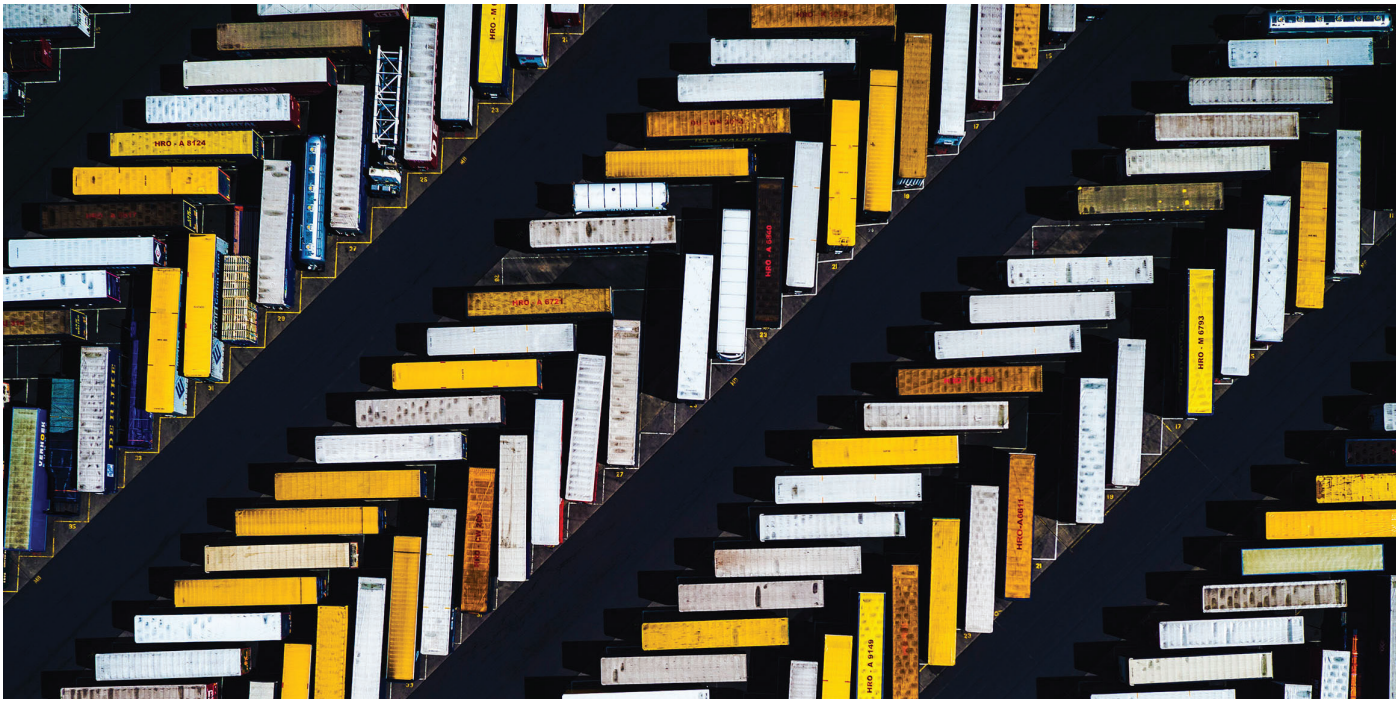
This can also occur as financial markets move with business cycles, causing fluctuations in market dynamics and shifts in the relationships between different signals. These cyclical patterns can create changes in the overall market structure, which in turn impacts the effectiveness of various signals. For example, during periods of economic expansion, certain signals related to growth-oriented companies or industries may exhibit stronger predictive power, whereas during periods of contraction, signals related to defensive or counter-cyclical sectors might become more valuable.

BlackRock's Systematic Investment Team has been working to continuously improve AIM by researching new approaches to address this challenge. One research direction we're exploring focuses on developing adaptive learning algorithms. These algorithms attempt to identify and adjust to changes in the distribution of financial data over time. By continuously monitoring the performance of the model and the characteristics of the input data, adaptive learning algorithms could detect shifts in the underlying distribution and update the model parameters accordingly. Techniques such as online learning, transfer learning, and domain adaptation could be explored in this context to develop more robust models that can better generalize from training data to live data.

Another promising research direction involves the incorporation of domain-specific knowledge and economic indicators into the model to better capture the underlying dynamics of financial markets. By incorporating information related to market cycles, macroeconomic factors, and other relevant data, the model may be better equipped to adapt to changes in the relationships between different signals.

Conclusion

As a proliferation of new data results in a multiplication of innovative new investment signals, AIM seeks to help systematic investors automate and better optimize the process of signal combination. AIM provides a customizable foundation for the creation of alpha models. The calibration and refinement of alpha models by expert portfolio managers brings this system to life — enabling models to be designed and optimized for navigating a wide range of investment objectives and market conditions.



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