
Quantifying Macroeconomic Risk

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Introduction

This paper is a collaboration between State Street Global Advisors and Qontigo, the new company formed from Axioma analytics and STOXX indices. State Street's Active Quantitative Equity (AQE) team and Qontigo Research have a long history of working closely together on risk modeling.

This paper builds on a series of Axioma presentations entitled "Quantifying Macro Risks,"¹ which detailed a framework for capturing macroeconomic risk effects in a fundamental equity risk model. Here we document how State Street researchers expanded this regional framework to a global context and applied it to Axioma's AXWW4 World-Wide Equity Factor Risk Model. Finally, we demonstrate how this global macroeconomic risk model can be used within an investment approach for exposure monitoring, risk analysis, performance attribution and portfolio construction.

Reformulating the Fundamental Risk Model in Terms of Macroeconomic Factors

Multiple-factor models are an essential component of portfolio risk management, optimized portfolio construction, stress testing, and return and risk attribution. These models decompose asset returns into systematic (factor) and idiosyncratic (specific) components, making it possible to estimate the asset returns covariance matrix that is used to measure portfolio risk, while simultaneously providing a “lens” through which portfolio returns and risk are explained.

Determining which model, or which “lens,” should be used to evaluate a particular portfolio or investment product is critical when monitoring that product. Fundamental factor models, which include a market factor, industry/country factors, and style factors, have become the de facto standard for many practitioners, since they are relatively easy to interpret and are often thought to capture most, if not all, of the systematic risk associated with broad market portfolios and indices.

What fundamental models lack, however, is a view on macroeconomic risk, such as that from interest rate, credit, commodity, and other exposures. To address this shortcoming, one could build a time series model from both macroeconomic and fundamental factors, or one could incorporate macroeconomic time series sensitivities into a fundamental model, but these efforts are challenging since macroeconomic factors are often correlated (and sometimes highly correlated) with fundamental factors.

Recognizing that macroeconomic factors can span the same space as the factors in a fundamental model, we propose a method for projecting fundamental factor returns onto macroeconomic factor returns and reformulating the fundamental risk model in terms of the macroeconomic factors, thus generating a macroeconomic model. This method makes it possible to quantify macroeconomic risk without having to estimate a full model from macroeconomic, market, and fundamental data. A framework for this model was first presented by Axioma in 2016 at its annual investor conference. Over the next two years, researchers from State Street’s Active Quantitative Equity team used this flexible framework as an initial basis to develop, test, and implement a global macroeconomic risk model.

The Core Framework

Qontigo's core framework starts with a single-country fundamental model that relates asset returns, r , to factor exposures, X , factor returns, f , and specific returns, ϵ .

$$(1) \quad \mathbf{r} = \mathbf{X}\mathbf{f} + \boldsymbol{\epsilon}$$

where $\text{var}(f) = \Sigma_{ff}$ and $\text{var}(\epsilon) = \Sigma_{\epsilon\epsilon}$.

Under the assumption that $\text{cov}(f, \epsilon) = 0$, the associated fundamental risk model is given by

$$(2) \quad \text{var}(\mathbf{r}) = \mathbf{X}\Sigma_{ff}\mathbf{X}' + \Sigma_{\epsilon\epsilon}$$

We posit that the fundamental factor returns, f , are a linear function of a set of macroeconomic returns, g , via

$$(3) \quad \mathbf{f} = \boldsymbol{\beta}\mathbf{g} + \boldsymbol{\delta}$$

Combining equations (1) and (3) yields a new returns model

$$(4) \quad \mathbf{r} = \mathbf{X}\boldsymbol{\beta}\mathbf{g} + \mathbf{X}\boldsymbol{\delta} + \boldsymbol{\epsilon}$$

and a new risk model

$$(5) \quad \text{var}(\mathbf{r}) = [\mathbf{X}\boldsymbol{\beta} \quad \mathbf{X}] \begin{bmatrix} \Sigma_{gg} & \Sigma_{g\delta} \\ \Sigma'_{g\delta} & \Sigma_{\delta\delta} \end{bmatrix} \begin{bmatrix} \boldsymbol{\beta}'\mathbf{X}' \\ \mathbf{X}' \end{bmatrix} + \Sigma_{\epsilon\epsilon}$$

specified in terms of the macroeconomic factors g , the residual fundamental factor returns δ , and the specific returns ϵ . To generate this new risk model, all that we need to estimate are the coefficients $\boldsymbol{\beta}$ in (3) and the factor covariance matrix in (5).

Under the assumption that $\text{cov}(g, \delta) = 0$, the macroeconomic model in (5) simplifies to

$$(6) \quad \text{var}(r) = [X\beta \ X] \begin{bmatrix} \Sigma_{gg} & \mathbf{0} \\ \mathbf{0} & \Sigma_{ff} - \beta \Sigma_{\delta\delta} \beta' \end{bmatrix} \begin{bmatrix} \beta' X' \\ X' \end{bmatrix} + \Sigma_{\epsilon\epsilon}$$

The benefit of this formulation is that risk predictions generated using (6) are the same as those generated using the original fundamental model (2) in expectation.² This formulation reinforces the idea that the new macroeconomic model is simply a linear transformation of the original fundamental model. Total risk predictions generated by the macroeconomic and fundamental models are the same; it's the focus of the models that differs, with the macroeconomic model explaining portfolio risk by the macroeconomic factors first.

The core framework described thus far assumes that we are starting from a single-country fundamental model. State Street and Qontigo embarked on this collaboration in order to recast a *global* fundamental model that includes both non-currency and currency factors. The method used is a bit more complicated, and hence is described in detail in Appendix A.

Creating a Macroeconomic Risk Model

The team of State Street researchers seeking to adapt the initial framework to create a macroeconomic risk model encountered a set of important initial choices. Qontigo's flexible framework allows for the incorporation of a wide range of macroeconomic factors into a standard fundamental risk model. There are, however, practical considerations that should be taken into account when performing factor selection. First, the selection of factors should align with those relevant to the investment strategy. The manager of a sector-specific portfolio may want to consider a more nuanced set of factors than the manager of a global multisector portfolio.

Second, it is important to select a set of tradable macroeconomic factors that have daily or weekly observable returns. This is to avoid the pitfalls of trying to incorporate low-frequency, non-tradable macroeconomic factors, such as reported GDP, into the risk model.³

Finally, if the estimation of the sensitivities β is done through least squares projection, it is also important to select factors that are not highly correlated with each other to avoid issues associated with multicollinearity.

With these considerations in mind, State Street researchers settled on five additional factors to recast the standard fundamental model:⁴ changes in interest rates (both shift and slope), energy prices, precious metal prices, and high-yield credit spreads. Figure 1 provides the factor definitions.

Figure 1
**Definitions of the Factors
Used to Recast the
Fundamental Model**

Factor Name	Variable Definition	Type	Bloomberg Ticker
Interest Rate Shift	First Principal Component of the US Yield Curve	Difference	N/A
Interest Rate Slope	Second Principal Component of the US Yield Curve	Difference	N/A
Credit Spreads	Bloomberg Barclays Global High Yield OAS Index	Difference	LG30OAS
Energy Prices	Bloomberg Energy Index	Return	BCOMENTR
Precious Metals	Bloomberg Precious Metals Index	Return	BCOMPRTR

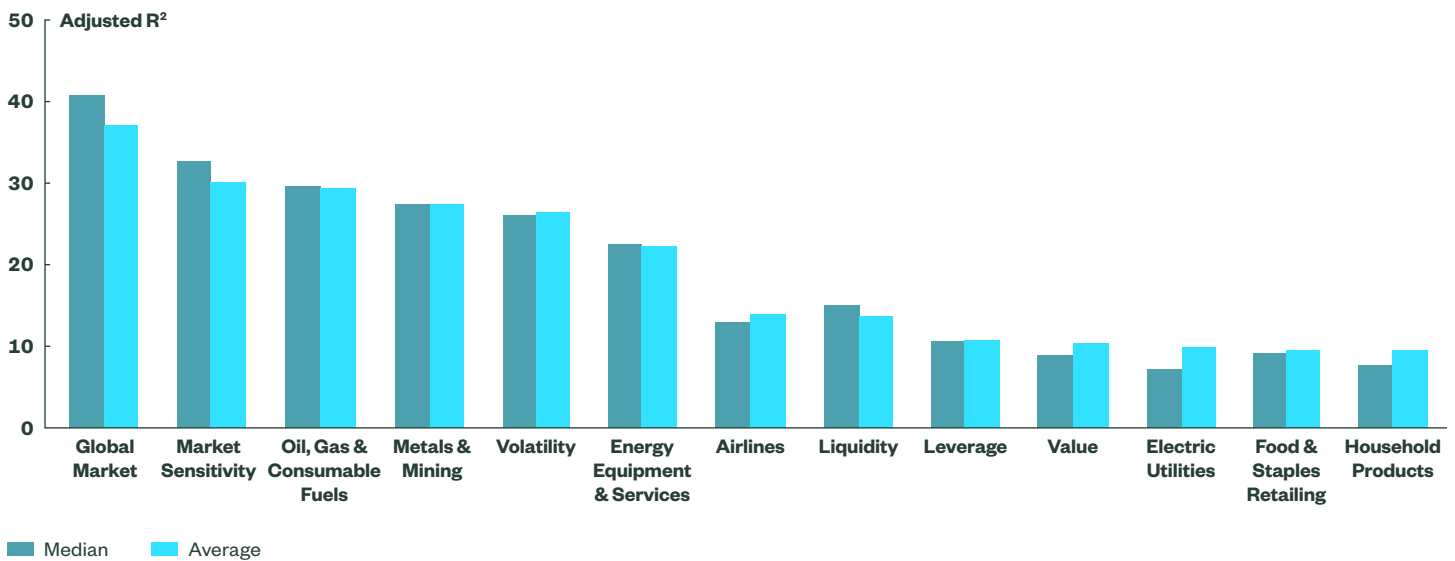
Source: State Street Global Advisors AQE, Bloomberg LLP, as of December 31, 2018.

As a group, these exogenous variables aim to capture the influence of traditional macro effects, such as growth and inflation expectations, as well as the influences of political, fiscal, and monetary policy decisions. The adjusted risk model uses the same return frequency, history length, and weighting scheme as those discussed in Appendix A to estimate β . Future research may consider different return frequencies, histories, and weighting schemes, as well as using other economic variables.

Before evaluating the full recast covariance matrix given by (6), we first examine the estimates of β in (3) to ensure that the macroeconomic factor returns explain a reasonable portion of the fundamental factor returns.

It is possible to assess the relevance of the macroeconomic factors by looking at the goodness of fit (adjusted R^2) for a handful of factors in the AXWW4 model. We find that aggregate, market-based factors, such as the Global Market, Market Sensitivity, and Volatility factors, are better explained by the macroeconomic variables than by company-specific factors, such as Profitability. Additionally, the R^2 statistics are typically higher for industries that are closely tied to the underlying variables, like Metals and Mining, as shown in Figure 2. These R^2 statistics provide assurance that the macroeconomic factors explain a reasonable portion of the fundamental factor returns.

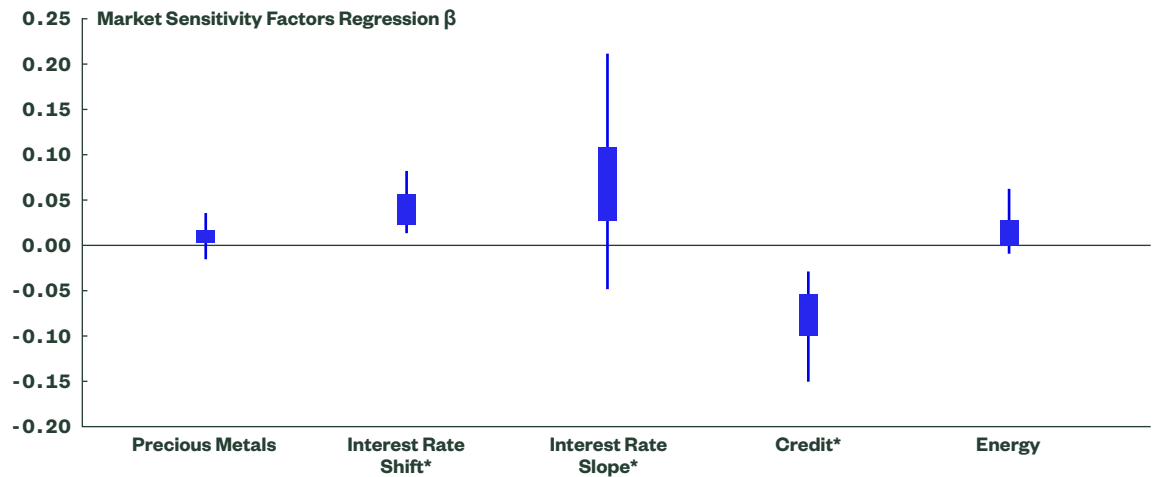
Figure 2
**Macroeconomic Factors’
 Explanatory Power,
 Adjusted R^2 , for
 AXWW4 Factors**



Source: State Street Global Advisors AQE, Qontigo, as of December 31, 2018.

In addition to verifying the relevance of the macroeconomic factors, we examine the sensitivities themselves to ensure that they are intuitive and reasonably stable over time. The Market Sensitivity factor, due to its high explanatory power, illustrates the potential impact of the macroeconomic factors. Our expectation is that the Market Sensitivity factor, which is synonymous with beta, would typically have a negative exposure to credit spreads (associated with a “risk off” environment) and positive exposure to interest rates (typically “risk on”). This expectation is confirmed by looking at the distribution of the coefficients β for the Market Sensitivity factor in Figure 3, where credit spread exposures tend to be negative, interest rate exposures tend to be positive, and the exposures of the other macroeconomic factors can be positive or negative (indicating that there is no consistent tilt for these factors).

Figure 3
Macroeconomic Regression Coefficient (β) for the AXWW4 Market Sensitivity Factor



Source: State Street Global Advisors AQE, Qontigo, as of December 31, 2018.

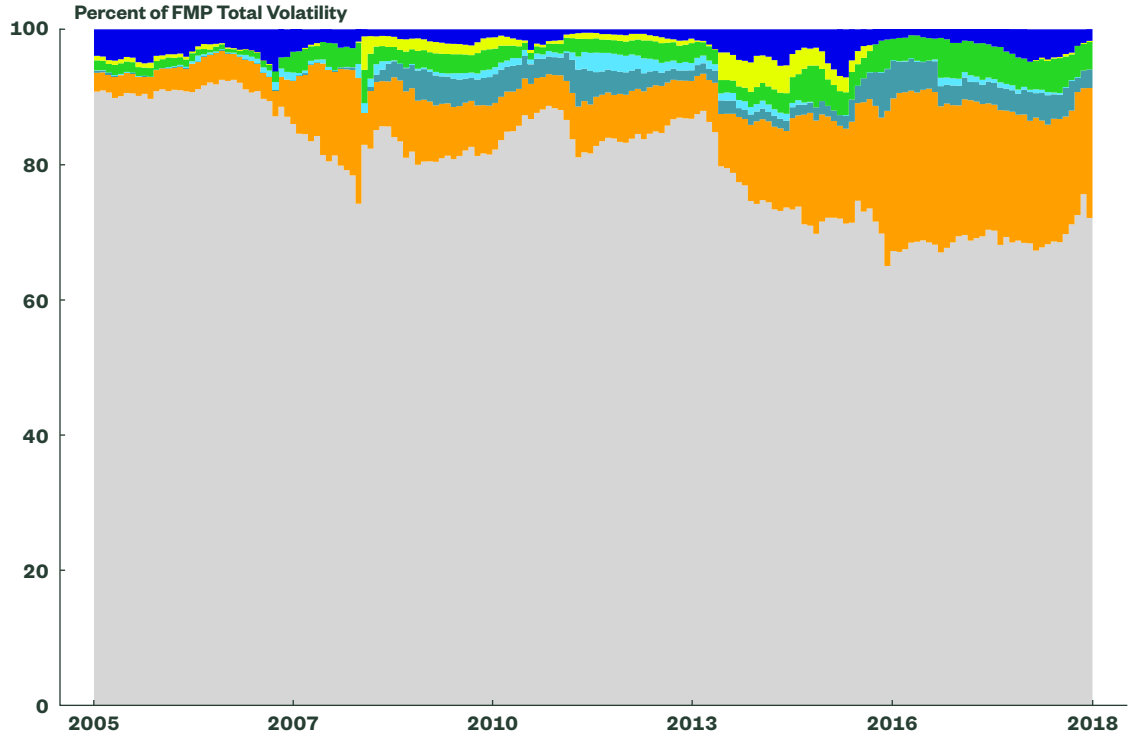
* Beta (β) scaled by a factor of 0.1.

This analysis can be taken further by using the adjusted risk model to perform a total risk decomposition of the Market Sensitivity factor-mimicking portfolio (FMP) from the AXWW4 model. An FMP is a long-short portfolio that has unit exposure to the factor it mimics and no exposure to the other factors in the model with which it is associated. By definition, the ex-ante risk of an AXWW4 FMP, when viewed through the lens of the AXWW4 model, is attributed entirely to one factor (the factor it mimics) and specific effects. When viewed through the lens of the adjusted risk model, in contrast, the ex-ante risk of an AXWW4 FMP is explained by the macroeconomic risk factors, the residual fundamental factor that it mimics, and specific effects.

Figure 4 presents the AXWW4 Market Sensitivity FMP risk decomposition with the adjusted risk model. Here we see that, towards the end of the time series, almost a third of the Market Sensitivity FMP volatility is explained by the Credit, Interest Rate, and Energy factors, with the majority of risk attributed to the Credit factor.

Figure 4
Market Sensitivity
FMP Percent of Risk
Decomposition

- Specific
- Interest Rate Slope
- Interest Rate Shift
- Precious Metals
- Energy
- Credit
- Market Sensitivity



Source: State Street Global Advisors AQE, Qontigo, as of December 31, 2018.

We repeat this exercise for all the style FMPs and present the time series average of the FMP volatility decompositions grouped into factor, macroeconomic, and specific risk contributions in Figure 5. While the macroeconomic factors explain some of the variance in all of the AXWW4 Style FMPs, they play a more significant role in the Market Sensitivity and Volatility FMPs. This picture is consistent with the results in Figure 2, which presents the proportion of the variance in individual fundamental factor returns that is explained by the macroeconomic factors (the adjusted R^2).

Figure 5
**Average Percent of Total
Volatility Contributions
for Style FMPs**
2005–2018; Standard
Deviations in Parenthesis

Factor Name	FMP Factor Risk (%)	Macro Factor Risk (%)	Specific Risk (%)
Market Sensitivity	80.3	17.1	2.6
	(8.1)	(8.1)	(1.4)
Volatility	80.9	13.8	5.3
	(5.3)	(5.6)	(2.3)
Value	74.1	7.1	18.8
	(4.9)	(5.8)	(6.2)
Liquidity	76.6	6.6	16.8
	(4.5)	(3.1)	(5.0)
Medium-Term Momentum	86.5	6.1	7.4
	(2.6)	(3.4)	(3.3)
Leverage	70.7	5.2	24.1
	(5.0)	(3.8)	(6.4)
Dividend Yield	76.5	3.8	19.7
	(4.6)	(3.3)	(6.2)
Exchange Rate Sensitivity	70.1	3.4	26.4
	(6.0)	(2.2)	(6.8)
Growth	68.4	2.8	28.8
	(7.3)	(2.9)	(8.8)
Earnings Yield	70.7	2.8	26.5
	(5.4)	(2.6)	(6.3)
Size	89.7	2.6	7.6
	(2.4)	(1.7)	(2.0)
Profitability	63.3	2.0	34.7
	(6.6)	(2.4)	(7.8)

Source: State Street Global Advisors AQE, Qontigo, as of December 31, 2018.

While the analysis in this section is limited to theoretical, style FMPs and excludes the country and industry factors in the AXWW4 model, which will also have exposure to the macroeconomic factors, it does demonstrate the impact of the projection and shows that non-equity risk factors can explain a reasonable portion of the risk of some of the fundamental factors.

Recognizing that real-world portfolios are rarely, if ever, exposed to just one risk factor, we now turn our attention to a more realistic portfolio environment and focus on how investors would use the adjusted model in this context. Before doing so, it is important to reiterate that the total risk estimates generated by the adjusted model are identical to those generated by the AXWW4 model; as a result, we need not examine overall risk predictions and their accuracy, since the AXWW4 model is widely accepted as a well-defined and powerful risk model. Rather, we focus on the decomposition of returns and risk made possible by the adjusted risk model, examining portfolio behavior through the new lens that it provides.

Simulating a Momentum Strategy and Using the Adjusted Model

The State Street research team prepared a simulated portfolio to demonstrate some uses of the adjusted risk model and the potential benefits it can bring to investors. The simulated portfolio is a systematic long-only momentum strategy, which we shall refer to as the “momentum strategy.” The use of a momentum strategy is motivated by the time-varying macroeconomic risk exposures that these strategies are known to take.⁵

To build the momentum strategy, an alpha signal is produced using a blend of consensus earnings upgrades and historical 11-month price momentum lagged by 1 month. This simplified strategy is akin to a smart beta momentum strategy and is selected purely for illustrative purposes. See Appendix B for further details on how it was constructed.

To ensure that the strategy is representative of a typical long-only quant manager, the optimization is subject to constraints on sector, country, stock, and Axioma style exposures, relative to the FTSE World Index. Momentum and Market Sensitivity exposures are not constrained (Momentum is excluded for obvious reasons; Market Sensitivity is excluded to allow the portfolio to modulate its market exposure). Figure 6 provides summary statistics for the strategy for the 2005–2018 test period, and Figure 7 depicts the strategy’s annual performance over time.

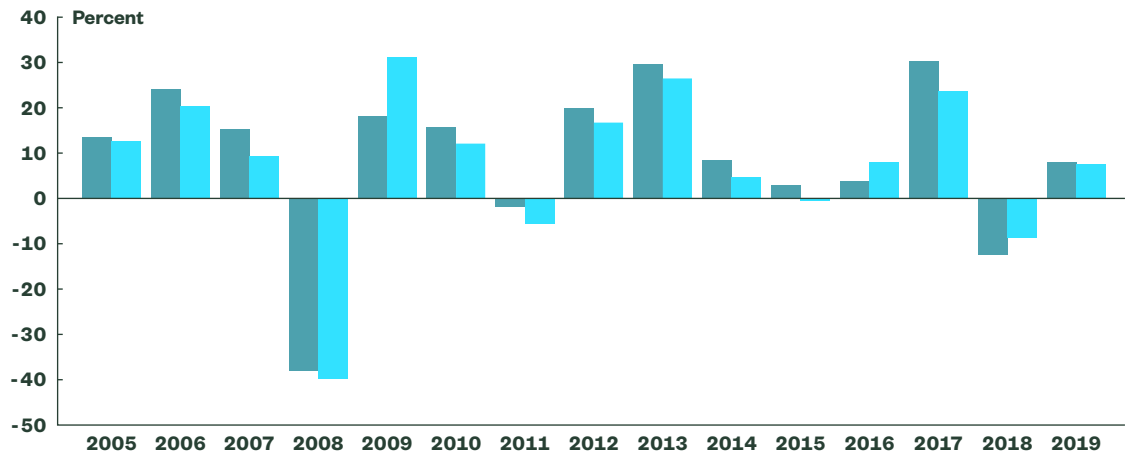
Figure 6
**Summary Statistics for
 Simulated Momentum
 Strategy (2005–2018)**

	Momentum Strategy
Active Return (p.a)	1.34%
Tracking Error (Ex-post)	4.33%
Information Ratio	0.31
Max Active Drawdown	-19.75%
Average Monthly Turnover (one way)	5.88%
Average Monthly Turnover Expense	0.20%
Average Alpha Model Transfer Coefficient	0.17
Average Axioma Medium Term Momentum Exp	0.46
Average Active Share	82.92%
Average Number of Stocks	252

Source: State Street Global Advisors AQE, as of December 31, 2018.

Figure 7
Yearly Performance of Simulated Momentum Strategy

■ Momentum Strategy
 ■ FTSE World Index



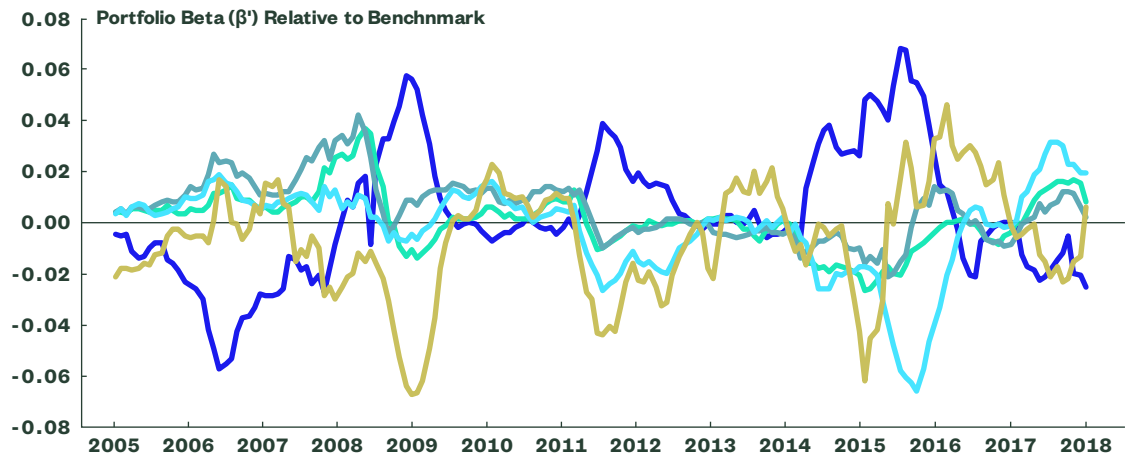
Source: State Street Global Advisors AQE, FTSE Russell, as of December 31, 2018.

Risk Exposure Monitoring

Portfolio exposure monitoring is a natural starting point for assessing the utility of the adjusted risk model, since it reveals the intended and unintended bets a portfolio may take. Figure 8 shows the momentum strategy's macroeconomic exposures over time, measured relative to the FTSE World Index. It is clear from this figure that the strategy is exposed to all of the macroeconomic factors in the adjusted model at one point of time or another, with more extreme exposures taking place at distinct points in time (2009, 2012, and 2016). This information is not revealed through a traditional fundamental risk model lens; it is only through the adjusted model that we gain insight into these macroeconomic dependencies.

Figure 8
Time Series of Active Macroeconomic Exposures for Momentum Strategy vs. FTSE World

■ Credit*
 ■ Energy
 ■ Precious Metals
 ■ Interest Rate Shift*
 ■ Interest Rate Slope*

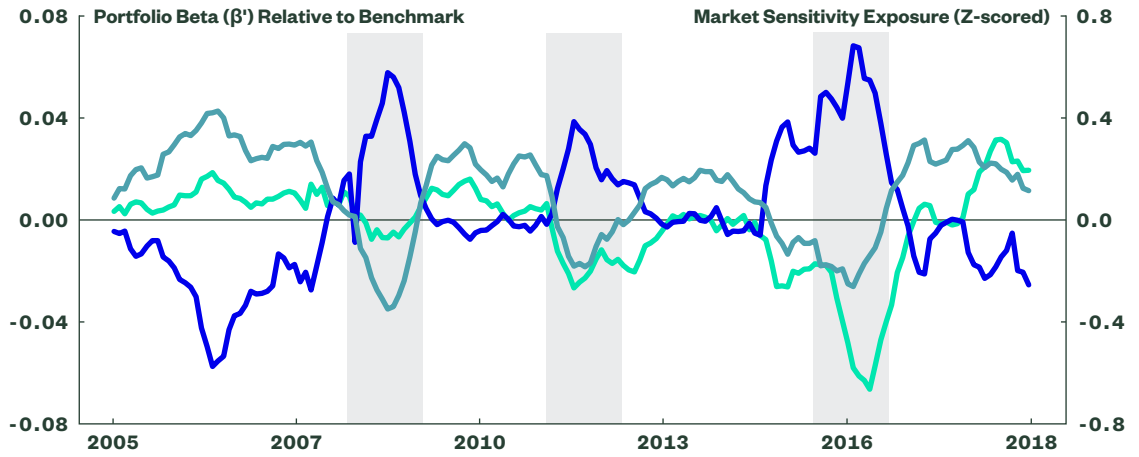


Source: State Street Global Advisors AQE, FTSE Russell, as of December 31, 2018.
 * Beta (β') scaled by a factor of 0.1.

To elaborate on this, we focus on a subset of factors, and examine the periods following the Global Financial Crisis, the Eurozone Crisis, and the period of high equity market volatility in 2015 and 2016 (Figure 9). Looking at the Market Sensitivity and Credit Spread exposures, it is clear that the portfolio takes on an increasingly defensive position during each of these three periods.

Figure 9
A Subset of Macroeconomic Factor Exposures Highlighting Changes that Follow Periods of Market Volatility

■ Interest Rate Shift*
 ■ Credit*
 ■ Market Sensitivity (RHS)



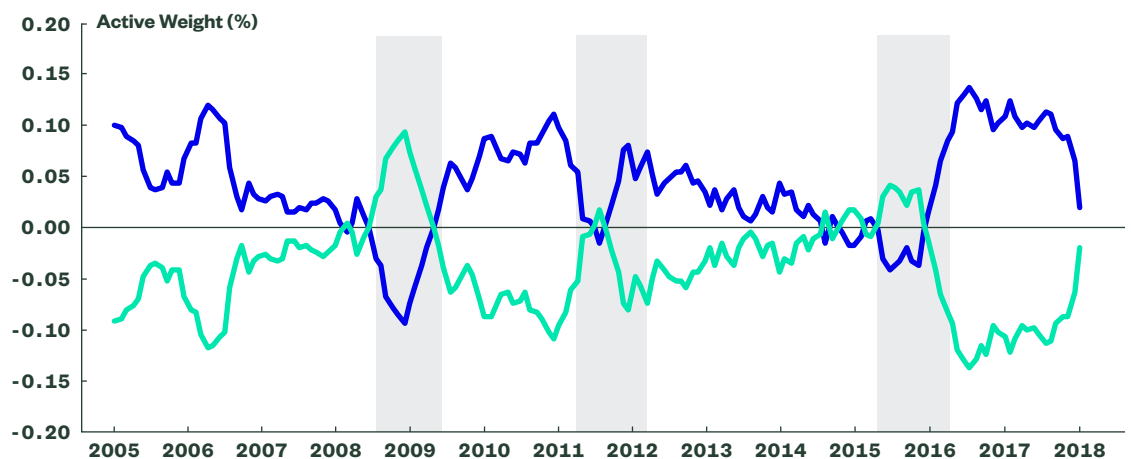
Source: State Street Global Advisors AQE, FTSE Russell, as of December 31, 2018.
 * Beta (β') scaled by a factor of 0.1.

One key difference, however, is the portfolio's exposure to the interest rate shift factor. During 2016, the strategy was significantly more sensitive to interest rate movements, reaching an extreme negative exposure in mid-2016. We suspect this difference is explained by market dynamics: In mid-2016, investors started to second-guess the Federal Reserve commitment to hiking interest rates due to growth concerns, which led to the US 10-year yield hitting an all-time low; the portfolio became increasingly sensitive to interest rate dynamics as a result (and far more sensitive than it was following the Global Financial and Eurozone crisis periods).

One might wonder whether the strategy had materially different sector exposures during 2016, since different sector loadings could explain the different interest rate sensitivities. Figure 10 presents the portfolio exposure to defensive versus cyclical sectors during this time. Here we see similar aggregate sector tilts over the highlighted periods, which suggests that different sector exposures do *not* explain the different interest rate sensitivities and supports the theory that market dynamics explain the more extreme interest rate positioning in 2016.

Figure 10
Portfolio Exposure to Defensive vs. Cyclical Sectors

■ Cyclical
 ■ Defensive



Source: State Street Global Advisors, Qontigo, as of December 31, 2018.

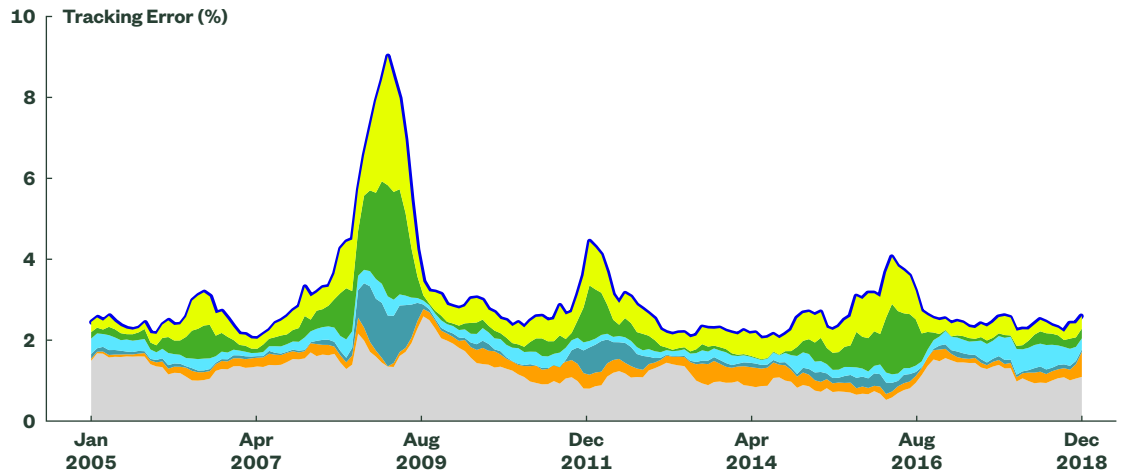
Exposure monitoring using the adjusted risk model has brought to light subterranean market dynamics and provided vital information on portfolio positioning that would not have been apparent using the AXWW4 World-Wide Equity Factor Risk Model lens. Monitoring macroeconomic exposures is useful, but looking at this alone misses the impact of the underlying macroeconomic factor volatilities and correlations. To tackle this, the adjusted risk model can be used to perform risk decompositions, which we discuss in the next section.

Risk Decompositions

Figure 11 presents the momentum strategy's ex-ante tracking error decomposition relative to the FTSE All World index using the adjusted risk model.

Figure 11
Ex-Ante Tracking Error Decomposition Adjusted Risk Model

- Active Risk
- Style
- Macro
- Industry
- Currency
- Country
- Specific

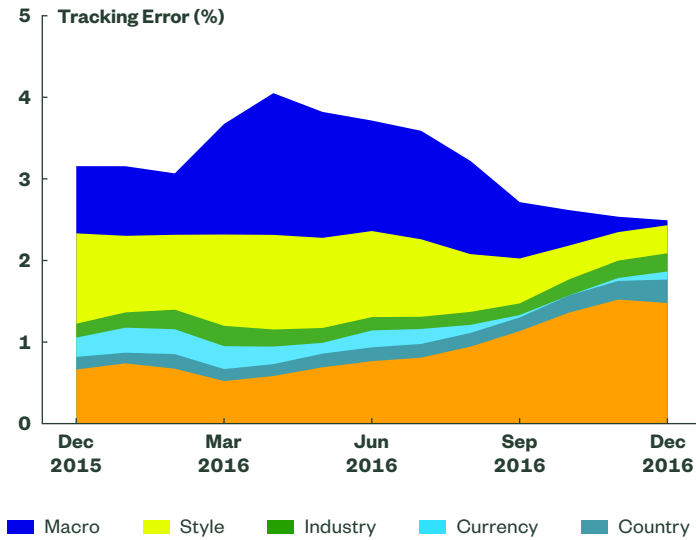


Source: State Street Global Advisors, Qontigo, as of December 31, 2018.

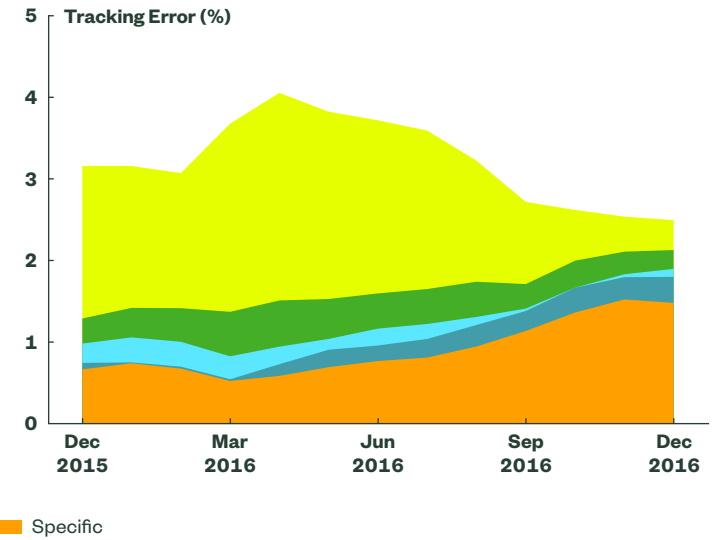
Comparing this plot with the exposures in Figure 8, we see that tracking error contributions from the macroeconomic factors need not be commensurate with the macroeconomic exposures. This is to be expected, since risk contributions are a function of factor exposures, volatilities, and correlations. Notwithstanding this, we find that there are periods where the risk from the macroeconomic variables is an important driver of tracking error.

Figure 12
Active Risk Decomposition
During 2016 Using the
Adjusted Risk Model
and AXWW4

Adjusted Risk Model



WW4 Risk Model



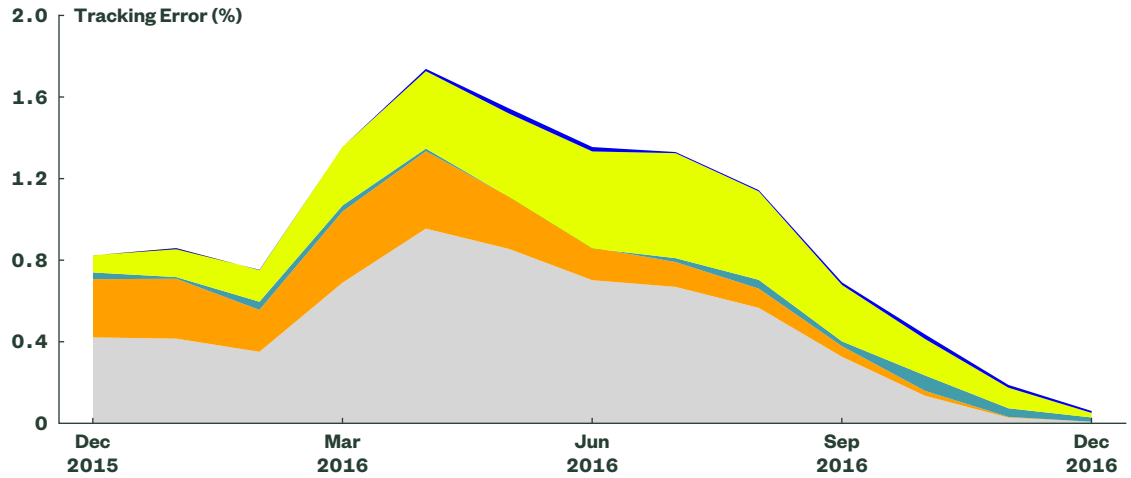
Source: State Street Global Advisors, Qontigo, as of December 31, 2016.

Figure 12 presents the tracking error decomposition during the 2016 sub-period using the adjusted risk model lens (left) and the AXWW4 World-Wide Equity Factor Risk Model lens (right). Comparing these decompositions side-by-side reveals that the strategy is exposed to significant macroeconomic risk concentrations in the first half of 2016. These concentrations are not identified in the AXWW4 model and hence are captured by the style, industry, and country factors in that model.

Figure 13 presents the individual macroeconomic factor contributions to tracking error over this period. Here we see that the Credit Spread, Interest Rate Shift, and Energy factors account for most of the macroeconomic contribution to tracking error.

Figure 13
Ex-Ante Tracking Error Decomposition from Macro Factors

- Interest Rate Slope
- Interest Rate Shift
- Precious Metals
- Energy
- Credit



Source: State Street Global Advisors, Qontigo, as of December 31, 2016.

Given that the challenge for any investment manager is to balance the trade-off between risk and return, having information about macroeconomic factor risk is critical. Armed with information about macroeconomic risk concentrations, which were previously unknown, investment managers can determine whether these risks are being suitably rewarded. If macroeconomic concentrations become outsized as defined by their marginal contributions to risk, portfolio positioning can be adjusted accordingly.

Performance Attribution

Recognizing that risk predictions are forward-looking measures, we now turn to attribution analysis, using the adjusted returns model in equation (4) to decompose the realized returns of the sample portfolio. As with any Axioma Risk Model, the adjusted model can be used for factor-based performance attribution.

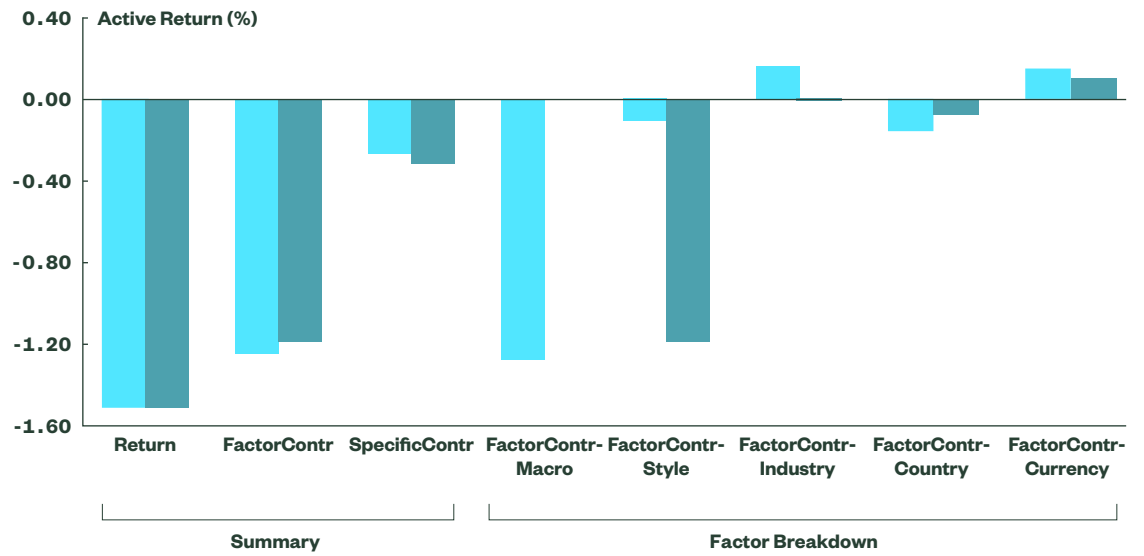
In an ideal world, outperformance or underperformance of the simulated momentum strategy would be primarily attributed to the momentum factor, since this factor is positively correlated with the alpha model used to construct the portfolio. In reality, this is not always the case, particularly when the portfolio being analyzed is exposed to other factors.

Figure 14 depicts the active return attribution of the simulated momentum strategy relative to the FTSE All World index. In March and April of 2016, when the strategy underperformed the FTSE All World by 1.50%, almost all of that underperformance is attributed to the macroeconomic factors (when using the adjust risk model) versus style factors (when using the AXWW4 model). More specifically, the adjusted attribution shows that Credit (-69bps), Energy (-42bps), and Precious Metals (-19bps) all contributed negatively to performance.

It is interesting to note that the non-equity factors are able to fully explain this period of underperformance. Obviously, this is just a snapshot of performance, but these results beg the question: Can we improve the strategy by hedging macroeconomic risk?

Figure 14
Risk Factor
Attribution Summary
 March–April 2016

Macro
 WW4



Source: State Street Global Advisors, Qontigo, as of April 30, 2016.

Using the Adjusted Model for Portfolio Construction

To demonstrate how the adjusted risk model can be used in portfolio construction, the State Street team investigated the impact of hedging macroeconomic risk using Axioma Portfolio Optimizer. It is important to note that this exercise is made trivial by the fact that the adjusted risk model has the same structure as the base model (Axioma's AXWW4 World-Wide Equity Factor Risk Model) and hence is directly compatible with the Axioma Portfolio Optimizer.

We re-estimate the momentum strategy using the same utility function and constraints outlined previously, but this time we add new constraints to limit macroeconomic risk exposures, generating a “macroeconomic-constrained momentum strategy.” Figure 15 provides a summary of the performance characteristics of the two momentum strategies. Adding the macroeconomic constraints increases the active return and information ratio of the strategy. The key to this improved performance becomes apparent when comparing the two strategies' drawdown profiles (see Figure 16).

Figure 15
Summary Performance Statistics for the Momentum Strategy and Macroeconomic-Constrained Momentum Strategy (2005–2018)

	Momentum Strategy	Macroeconomic-Constrained Momentum Strategy	Difference
Active Return (p.a)	1 . 34%	1 . 65%	23%
Tracking Error	4 . 33%	3 . 30%	- 24%
Information Ratio	0 . 31	0 . 50	61%
Max Active Drawdown	- 19 . 75%	- 8 . 42%	- 57%
Average Monthly Turnover (one way)	5 . 88%	5 . 87%	0%
Average Monthly Turnover Expense	0 . 20%	0 . 20%	0%
Average Alpha Model Transfer Coefficient	0 . 17	0 . 16	- 5%
Average Axioma Medium Term Momentum Exp	0 . 46	0 . 42	- 10%
Average Active Share	82 . 92%	82 . 39%	- 1%
Average Number of Stocks	252	252	0%

Source: State Street Global Advisors, as of December 31, 2018.

Figure 16a

Active Returns for the Momentum Strategy and Macroeconomic-Constrained Momentum Strategy

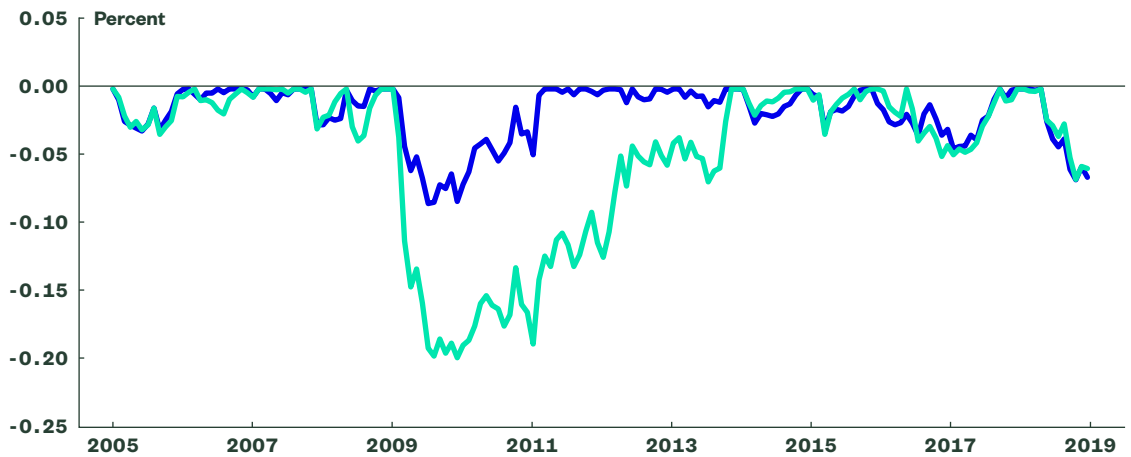
- Momentum Strategy
- Macroeconomic-Constrained Momentum Strategy
- FTSE World Index



Figure 16b

Drawdown Profiles for the Momentum Strategy and Macroeconomic-Constrained Momentum Strategy

- Macroeconomic-Constrained Momentum Strategy
- Momentum Strategy



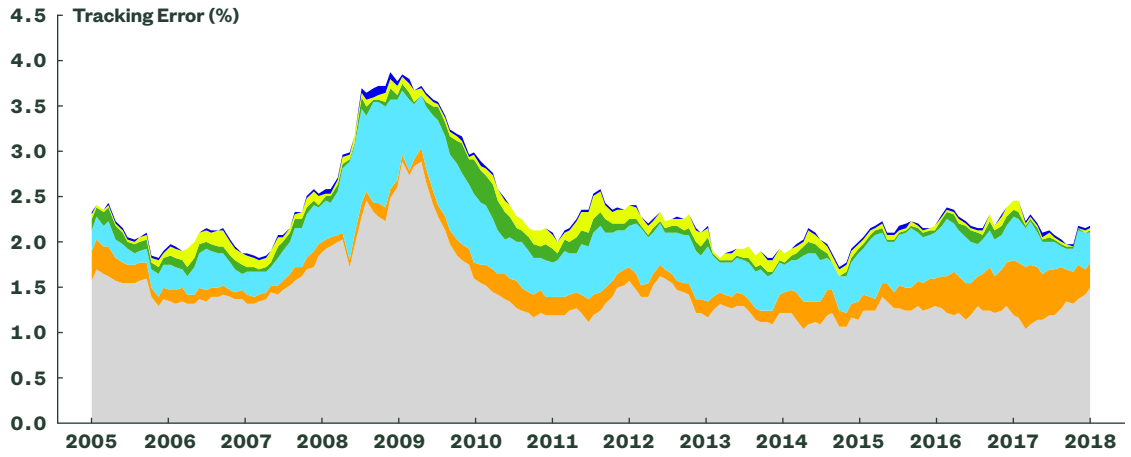
Source: State Street Global Advisors, as of December 31, 2018.

Hedging macroeconomic exposures has materially reduced the drawdown in the macroeconomic-constrained momentum strategy relative to the original momentum strategy. The effect is most notable during 2009, when the unconstrained portfolio was heavily exposed to a continued widening of the credit spread.

Drilling into the ex-ante risk profile (Figure 17) shows how adding this simple constraint has reduced the overall tracking error of the fund. The hedged strategy no longer has the spikes in tracking error that coincided with periods of high macroeconomic exposure in the original strategy. Further, the tracking error decomposition in Figure 17 displays a more consistent risk profile over time, in which contributions from factor groups remain fairly steady.

Figure 17
Ex-Ante Risk Profile of the Macroeconomic-Constrained Momentum Strategy

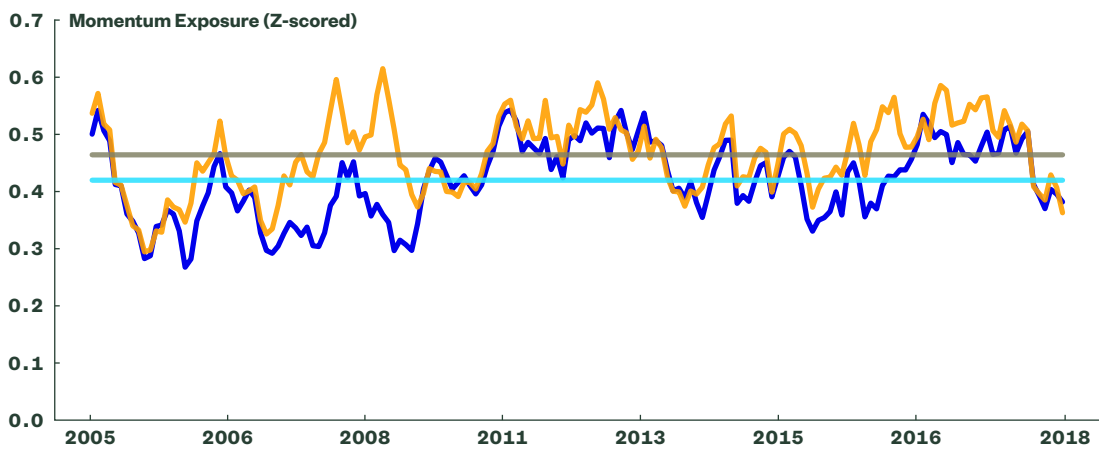
- Macro
- Country
- Currency
- Style
- Industry
- Specific



Source: State Street Global Advisors, Qontigo, as of December 31, 2018.

Figure 18
Axioma Medium-Term Momentum Factor Exposure

- Macroeconomic-Constrained Momentum Strategy
- Momentum Strategy
- Average Macroeconomic-Constrained Momentum Strategy
- Average Momentum Strategy



Source: State Street Global Advisors, Qontigo, as of December 31, 2018.

As with any hedging, there is an associated cost. Figure 18 shows the portfolio exposures to the Medium-Term Momentum factor for the original momentum strategy and the macroeconomic-constrained momentum strategy. The latter strategy (the hedged strategy) is less exposed to the Medium-Term Momentum factor than the original strategy, which is directly in contrast with the goal of the alpha model. Still, the momentum exposures of the two strategies follow similar paths the vast majority of the time; it's only when the macroeconomic risk builds up that we see a divergence. Given that the hedged strategy has higher risk-adjusted returns than the original strategy, in addition to other desirable properties, the cost associated with having lower alpha exposure may be worth it.

Closing Thoughts

In this paper, Qontigo and State Street Global Advisors present a framework for creating a “macroeconomic risk model” from a fundamental equity risk model by projecting the fundamental factor returns against a set of macroeconomic factors and formulating a new, macroeconomic model in terms of these macroeconomic factors. This approach makes it possible to quantify macroeconomic risk effects without having to estimate a macroeconomic model from scratch, which is known to be challenging given the nature of macroeconomic data.

Our research demonstrates how to create a global macroeconomic model that measures macroeconomic risk from interest rates, credit spreads, commodity exposures, and more. It demonstrates how the macroeconomic model can be used for exposure analysis, risk analysis, performance attribution, and portfolio construction, providing portfolio and risk managers with new information about the intended (and unintended) bets a portfolio may take. This new insight is critical for making informed investment choices and achieving higher risk-adjusted returns in an increasingly dynamic macroeconomic environment.

Appendices

Appendix A: Deriving the Macroeconomic Model

Fundamental Model

This appendix describes the fundamental model that is the starting point of our analysis, and states the assumptions made to relate the fundamental factors to macroeconomic factors and recast the fundamental model as a macroeconomic model.

From the perspective a particular numeraire currency, N , the fundamental returns model is specified as

$$(A1) \quad r^N = X_n f_n + X_c f_c^N + \epsilon$$

where

- r^N is an m -dimensional vector of asset excess returns denominated in the numeraire currency
- X_n is an $m \times n$ matrix of exposures to the n non-currency factor returns, and f_n is the corresponding n -dimensional vector of non-currency factor returns,
- X_c is an $m \times c$ matrix of exposures to the c currency factors, and f_c is the corresponding c -dimensional vector of currency returns from the perspective of numeraire N , and
- ϵ is an m -dimensional vector of specific returns.

Under the assumptions that

$$\text{Cov}(\epsilon, f_n) = 0, \text{Cov}(\epsilon, f_c) = 0, \text{Var} \begin{pmatrix} f_n \\ f_c \end{pmatrix} = \begin{bmatrix} \Sigma_{nn} & \Sigma_{nc} \\ \Sigma'_{nc} & \Sigma_{cc} \end{bmatrix}, \text{ and } \text{Var}(\epsilon) = \Sigma_{\epsilon\epsilon}$$

the risk model is specified as

$$\text{var}(r^N) = [X_n \ X_c] \begin{bmatrix} \Sigma_{nn} & \Sigma_{nc} \\ \Sigma'_{nc} & \Sigma_{cc} \end{bmatrix} \begin{bmatrix} X'_n \\ X'_c \end{bmatrix} + \Sigma_{\epsilon\epsilon}$$

Since currency returns exhibit a range of behaviors that one needs to take into account when modelling currency risk (e.g., many currencies are pegged, many are illiquid), it is common practice to model currency risk separately, often using a statistical model, and then combine currency exposures and covariances with non-currency factor exposures and factor covariance matrix as the final step of generating the model. See *Axioma Research Paper 19, entitled "Currency Modeling in Axioma Robust Risk Models,"* for a complete derivation of the full returns model and risk model in a regional model.

Formulating the Macroeconomic Model

We take model (A1) as given, and posit that the non-currency factor returns in that model are a linear function of a p -dimensional vector of macroeconomic factor returns, denoted by g , via

$$(A2) \quad \mathbf{f}_n = \beta \mathbf{g} + \delta$$

where β is a $n \times p$ matrix of coefficients, δ is a n -dimensional vector of residual factor returns, $\text{Var}(g) = \Sigma_{gg}$, and $\text{Var}(\delta) = \Sigma_{\delta\delta}$.

Combining equations (A1) and (A2) gives a new returns model, specified in terms of the macroeconomic factors g and residual factor returns δ :

$$\mathbf{r}^N = \mathbf{X}_n \beta \mathbf{g} + \mathbf{X}_n \delta + \mathbf{X}_c \mathbf{f}_c^N + \boldsymbol{\epsilon}$$

Under the assumptions that

$$\text{Cov}(\boldsymbol{\epsilon}, \mathbf{g}) = \mathbf{0}, \text{Cov}(\boldsymbol{\epsilon}, \delta) = \mathbf{0}$$

our macroeconomic risk model becomes

$$(A3) \quad \text{Var}(\mathbf{r}) = [\mathbf{X}_n \beta \quad \mathbf{X}_n \quad \mathbf{X}_c] \begin{bmatrix} \Sigma_{gg} & \Sigma_{g\delta} & \Sigma_{gc} \\ \Sigma_{g\delta}^1 & \Sigma_{\delta\delta} & \Sigma_{\delta c} \\ \Sigma_{gc}^1 & \Sigma_{\delta c}^1 & \Sigma_{cc} \end{bmatrix} \begin{bmatrix} \beta \mathbf{X}_n' \\ \mathbf{X}_n' \\ \mathbf{X}_c' \end{bmatrix} + \Sigma_{\epsilon\epsilon}$$

Estimating the Macroeconomic Model

Estimating the macroeconomic model involves estimating two components:

- The macroeconomic factor covariance matrix

$$(A4) \quad \begin{bmatrix} \Sigma_{gg} & \Sigma_{g\delta} & \Sigma_{gc} \\ \Sigma_{g\delta}^1 & \Sigma_{\delta\delta} & \Sigma_{\delta c} \\ \Sigma_{gc}^1 & \Sigma_{\delta c}^1 & \Sigma_{cc} \end{bmatrix}$$

- The coefficients β that relates the non-currency factor returns to the macroeconomic factor returns

Once these have been estimated, it is trivial to construct the macroeconomic factor exposure and covariance matrices specified in equation (A3).

The macroeconomic factor covariance matrix in (A4) may be estimated as a sample covariance matrix. Alternatively, if $\text{cov}(g, \delta) \equiv \Sigma_{g\delta} = 0$, we can reformulate the factor covariance matrix as

$$(A5) \quad \begin{bmatrix} \Sigma_{gg} & 0 & \Sigma_{gc} \\ 0 & \Sigma_{nn} - \beta \Sigma_{gg} \beta' & \Sigma_{nc} - \beta \Sigma_{gc} \\ \Sigma'_{gc} & (\Sigma_{nc} - \beta \Sigma_{gc})' & \Sigma_{cc} \end{bmatrix}$$

recognizing that

$$\Sigma_{\delta, \delta} = \Sigma_{nn} - \beta \Sigma_{gg} \beta'$$

$$\text{Cov}(\delta, f_c) = \text{Cov}(f_n - \beta g, f_c) = \Sigma_{nc} - \beta \Sigma_{gc} \Rightarrow \Sigma_{\delta c} = \Sigma_{nc} - \beta \Sigma_{gc}$$

Formulating the factor covariance matrix in this way ensures that the risk predictions generated using the macroeconomic model are the same, in expectation, as the risk predictions generated using the original fundamental model, since

$$[X_n \beta \ X_n \ X_c] \begin{bmatrix} \Sigma_{gg} & 0 & \Sigma_{gc} \\ 0 & \Sigma_{nn} - \beta \Sigma_{gg} \beta' & \Sigma_{nc} - \beta \Sigma_{gc} \\ \Sigma'_{gc} & (\Sigma_{nc} - \beta \Sigma_{gc})' & \Sigma_{cc} \end{bmatrix} \begin{bmatrix} \beta' X'_n \\ X'_n \\ X'_c \end{bmatrix} = [X_n \ X_c] \begin{bmatrix} \Sigma_{nn} & \Sigma_{nc} \\ \Sigma'_{nc} & \Sigma_{cc} \end{bmatrix} \begin{bmatrix} X'_n \\ X'_c \end{bmatrix}$$

Alternatively, if one assumes that $\beta' = \Sigma_{gg}^{-1} \Sigma_{gn}$, the covariance matrix in (A4) simplifies to

$$(A6) \quad \begin{bmatrix} \Sigma_{gg} & 0 & \Sigma_{gc} \\ 0 & \Sigma_{nn} - \Sigma'_{gn} \Sigma_{gg}^{-1} \Sigma_{gn} & \Sigma_{nc} - \Sigma'_{gn} \Sigma_{gg}^{-1} \Sigma_{gc} \\ \Sigma'_{gc} & (\Sigma_{nc} - \Sigma'_{gn} \Sigma_{gg}^{-1} \Sigma_{gc})' & \Sigma_{cc} \end{bmatrix}$$

For the purpose of this paper, we use the factor covariance matrix in (A5). To estimate the components of that matrix, Σ_{gg} , Σ_{gc} , Σ_{nc} , Σ_{nn} and Σ_{cc} , we first estimate a covariance matrix of the macroeconomic returns g , the non-currency factors returns f_n , and the currency factor returns f_c , which we denote by

$$(A7) \quad \Sigma = \begin{bmatrix} \Sigma_{gg} & \Sigma_{gn} & \Sigma_{gc} \\ \Sigma'_{gn} & \Sigma_{nn} & \Sigma_{nc} \\ \Sigma'_{gc} & \Sigma'_{nc} & \Sigma_{cc} \end{bmatrix}$$

When we estimate the covariance matrix in (A7), we assume that variances and covariances follow different dynamics, using the well-known decomposition

$$\Sigma = \mathbf{VCV},$$

where V is a diagonal matrix of factor standard deviations, and C is a matrix of factor correlations.

Variances are estimated from 5 years of weekly returns, where the returns are weighted using an exponential weighting scheme with a half-life parameter of 26 weeks. The correlations in C are estimated from 5 years of weekly returns using a half-life parameter of 52 weeks. After estimating Σ , we perform a transformation⁶ to ensure that the non-currency and currency blocks match the original factor covariance matrix of the fundamental model (this ensures that differences resulting from sample variation — i.e., using daily versus weekly data — are not reflected in risk predictions).

Once we've estimated the covariance matrix in (A7), we can use its sub-blocks and our estimate of β (discussed in the next section) to formulate the macroeconomic factor covariance matrix in (A5).

Estimating the Relationship Between the Non-currency Factor Returns and the Macroeconomic Returns

What remains is to estimate β , the coefficients that relate the non-currency factor returns f_n to the macroeconomic returns g . This is done over time, using the estimate

$$\beta' = \Sigma_{gg}^{-1} \Sigma_{gn}$$

where Σ_{gg} is the covariance matrix of the macroeconomic returns and Σ_{gn} is the covariance matrix of the macroeconomic and the original factor returns.

We use the same return frequency, history length, and weighting scheme as those discussed in the previous sections to estimate β . Future research may consider different return frequencies, histories, and weighting schemes.

Appendix B: Creating a Time Series of Portfolio Holdings

To create a time series of portfolio holdings we use the Axioma Portfolio Optimizer and the Axioma AXWW4 World-Wide Equity Risk Model to maximise the following utility function

$$\max \alpha^T w - \eta TC(\Delta w) - \gamma (w^T \Sigma w)$$

where α is the momentum investment signal, w is the portfolio active weights, TC is a piece wise transaction cost matrix, Σ is the Axioma WW4 World-Wide Equity Risk Model covariance matrix, and η and γ represent transaction cost and risk aversion parameters. The portfolio is rebalanced monthly between Jan 2005 and Dec 2018 using the FTSE All World index as our investable universe.

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Endnotes

- 1 The series of presentations, "Quantifying Macro Risks," was first presented by Dieter Vandenbussche, Managing Director of Equity Research at Qontigo, in 2016, at Axioma's annual investor conference.
- 2 Risk forecasts generated using the fundamental and macroeconomic model are the same, barring sampling error. See Appendix A for a full derivation of the macroeconomic model that describes methods used to ensure risk forecasts between the fundamental and macroeconomic model are identical.
- 3 Traditional macroeconomic data, such as GDP, are generally released on a monthly or quarterly basis, often with release dates that lag the nominal date associated with data, and often with subsequent revisions. As a result, the timing at which the information content of traditional macroeconomic factors is revealed to market participants rarely matches the timing at which market prices are revealed, complicating the modelling process considerably. The model put forth in this paper assumes that the fundamental factor returns are explained by the contemporaneous returns of the macroeconomic factors, making it necessary to incorporate tradeable macroeconomic factors.
- 4 Axioma World Wide Fundamental Version 4 Risk Model (WW4).
- 5 M, Martens., and A. van Oord, 2014, Hedging the time-varying risk exposures of momentum returns. *Journal of Empirical Finance*, 28: 78–89.
- 6 See *Axioma Robust Risk Model Version 4 Handbook* for details on the Procrustes transform.

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