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Forward-Looking Scenario Analysis

Preparing your portfolio for the unknown unknowns

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Introduction

While historical stress scenario analysis is now a well-established approach in tail-risk management, there is less consensus on how best to perform forward-looking scenario analysis. In this paper, we examine how expert opinions about future world states can be incorporated into projections of portfolio outcomes. We also illustrate that using a diversified multi-asset approach can effectively help mitigate losses in such extreme market scenarios.
Forward-looking scenario analysis is a tool that can provide a more realistic assessment of the downside risks and upside potential of investment portfolios than traditional approaches. It captures the sensitivity of portfolios to events through the mathematical articulation of expert opinion. It challenges and enhances our understanding of likely portfolio behaviour in extreme scenarios. And it allows us to prepare for the unexpected.

Two common weaknesses in stress-testing methodologies were exposed by the financial crisis: an over-reliance on historical statistical relationships; and a lack of qualitative expert judgement.

Traditional risk models generally fail to capture the downside risks of portfolios during crises. They assume that market returns follow a normal distribution. They treat returns as ‘independent and identically distributed’ – like tossing a coin, where the result of the last throw has no impact on what comes next. They fail to take account of the fact that risk-assets become increasingly correlated in times of stress. This means most risk models significantly underestimate the probability – and impact – of ‘tail-events’; those extreme market moves that occur far more regularly than predicted under a normal distribution.

Scenario analysis uses data that more closely represent the actual returns of asset classes – and the variable correlations between them. We employ experts who analyse the fundamental drivers of market returns. We blend expert opinion with quantitative analysis to generate a forward-looking distribution of expected returns that is consistent with the expert views but appropriately informed by history.

In this paper, we describe how we use the mathematics of ‘maximum entropy’ to achieve this aim. This principal has a long history in the world of physics. The global financial crisis triggered an exploration of its potential to improve the robustness of stress-testing and scenario analysis.

This approach provides us with the expected behaviour when the unexpected happens. In particular, it allows portfolio managers to identify any unintended concentration risks in a portfolio.

We illustrate our approach in relation to the historic returns of the US equity and US credit markets to demonstrate that an approach incorporating multiple scenarios improves the fit to actual data. It captures the changing relationship between these markets at different points in the economic cycle.

We then use our approach to compare the impact of a single scenario – a theoretical China crisis – on two portfolios: a typical US institutional strategic asset allocation and a diversified multi-asset portfolio that targets absolute returns. The US institutional asset allocation combines long-only exposures to a limited number of markets. By contrast, the diversified multi-asset portfolio combines a mix of long-only exposures to a broader range of markets with long-short positions designed to extract relative value. We find that the absolute return portfolio is much more resilient in this scenario, significantly reducing the fall in value relative to that expected for the US institutional asset allocation. This is consistent with our expectations across a broad range of stress scenarios.

Forward looking scenario analysis better captures the pernicious nature of tail risks and helps to ensure that portfolio performance is robust to a range of possible states of the world. It is a powerful tool for asset managers to explore the potential weaknesses in their portfolios.
Recognising the inadequacies of value at risk (VaR) metrics in measuring portfolio risk, investment practitioners and regulators have increasingly focused on stress testing and scenario analysis as a means of exploring so-called tail risks.

However, while measuring portfolio behaviour under historical stress scenarios is now established practice in risk management, there is far less agreement on how to perform forward-looking scenario analysis.

Major regulators noted two common weaknesses in the stress testing methodologies used during the financial crisis, namely:

- lack of qualitative expert judgement
- over-reliance on historical statistical relationships such as correlations.

Ideally, a forward-looking scenario methodology should be able to integrate a limited set of expert opinions with all relevant financial market data. These inputs could then be translated into portfolio gains and losses.

In this paper, we aim to show how to:

- quantitatively construct a population of data points for tail-risk analysis
- blend expert opinion to produce estimates of tail behaviour for different assets
- examine the impact on a portfolio of a particular extreme stress scenario.

We then analyse the strategic asset allocation of a typical US institutional portfolio to illustrate the robustness of an absolute return investment strategy. We show the benefits of spreading return-seeking investment risk within a single portfolio, by investing across asset classes and geographies, and using long-only positions and long-short relative value positions.
Fat tails exist if you believe the market is a single-state distribution. Financial market data is often described as ‘fat-tailed’.

This implies that the true distribution of outcomes is not normal but skewed and has fatter tails. In other words, more extreme variations of return occur more often than would be predicted by normal models and they are biased towards falls in value.

Chart 1 highlights the fat tails commonly observed in financial data. It shows a histogram of historical daily returns for the US equity S&P 500 Total Return Index over a 17-year period to January 2018, together with a normal approximation.

Traditional risk systems assume that financial market returns are independent and identically distributed (i.i.d.) and follow a normal distribution. (An example of i.i.d. is the repeated tossing of a coin: we expect as many ‘heads’ as ‘tails’ and the outcome of any one toss of the coin should be unaffected by any other.)

It is well known that these models significantly underestimate the probability of so-called tail events. Although more complex models attempt to describe and simulate fat tails, these approaches are still essentially built on the belief that one single-state distribution exists. The output of these models incorporate skew and kurtosis, but can fail the common sense test once expert judgment is applied.

**Chart 1: Actual US equity return distribution versus a fitted normal curve**

Source: Bloomberg; authors’ computation as at January 2018
A more intuitive approach is to consider market behaviour as a function of many different states of behaviour. This better reflects our observations of actual correlations and asset return variations throughout a market cycle.

For instance, investors have long recognised that economies tend to oscillate between steady, low-volatility states (or ‘regimes’) characterised by economic growth and nervous, high-volatility states characterised by economic contraction. Let us consider the same return data of the S&P 500 Total Return Index but this time, we divide the daily returns into a ‘high-volatility’ regime (in red) and a ‘low-volatility’ regime (in blue). For each of these two regimes we fit a normal distribution (see Chart 2). Even with this simple approach, you can visibly note that the fat tails observed earlier become less apparent.

For the purpose of scenario analysis, this approach can be very useful as a ‘regime-switching’ model. This produces fat tails as well as ‘tail dependence’ without the need for exotic parameter estimates.

We are therefore able to relax the assumption that market returns are identically distributed, instead modelling market behaviour by using a large number of overlapping regimes. These are encoded as a library of Monte Carlo simulations (computational algorithms that rely on repeated random sampling to obtain numerical results; typically simulations are run many times over, in order to obtain the distribution of an unknown probability).

**Chart 2: Actual US equity return distributions for low and high-volatility regimes versus fitted values of normal distributions**

Source: Bloomberg, authors’ computation as at January 2018
Constructing future scenarios

How should investors construct scenarios to stress test their portfolios? Identifying unexpected shocks cannot be just a statistical exercise that simply extrapolates recent trends. Investment expertise is needed to build scenarios that share three characteristics: they must be plausible; offer an independent perspective; and be market relevant.

Expert opinion has been rightly questioned, and not only by politicians like Michael Gove looking to undermine the views of their critics. Expert Political Judgement by psychologist Philip Tetlock provides an empirical study of thousands of predictions made by political pundits over two decades. He found that expert predictions performed no better than a flip of a coin. However, the work of Tetlock and his peers – most notably Daniel Kahneman and Amos Tversky – have informed investors about the biases and noise that adversely impact our decision making.

Investment expertise is required to build plausible future scenarios. Experts have the knowledge and know-how to understand how markets are likely to respond to specified shocks. The diverse range of assets included in a multi-asset portfolio means that a similarly diverse range of expertise is required to build realistic scenarios.

An independent perspective helps counteract two behavioural biases. We are prone to anchor our views to our central forecast. In our process, we aim to counteract this bias by asking a different group of individuals to propose these scenarios to those involved in determining our baseline economic and market outlook. Insightful observers can help by posing the right questions, even if it is not themselves who know the answers.

We are also prone to ‘groupthink’. The abdication of individual responsibility can lead to an unhappy compromise that is too close to the central view. Or it can lead to more extreme scenarios as committee members egg each other on. We aim to minimise these risks in all of our investment processes. In building stress scenarios, we mitigate groupthink by asking individuals to develop the scenarios on their own.

This thinking leads us to use a five-step process to generate a range of stress scenarios.

1. Individual investment experts propose extreme but plausible outcomes, such as a debt crisis in China. These can be triggered by market events (such as an oil price spike), political developments, economic surprises or other shocks with the potential to impact markets.

2. The investment experts meet to debate the proposed scenarios. If they share the same fundamental drivers, they are combined. Evidence is required that the scenario has a non-zero probability. Scenarios deemed too implausible are rejected. Also eliminated are scenarios that are too close to our central forecast. The descriptions of the relevant scenarios are agreed. This includes suggesting measures to track the evolution of the scenario.

3. Investment experts on individual markets – equities, fixed income, currencies and volatility – provide forecasts of the direction and magnitude of the likely impact on their market of each scenario.

4. The risk team combine these forecasts into a model to stress-test portfolios, quantifying the sensitivity to the different scenarios.

5. The investment experts, portfolio managers and risk managers meet to discuss the outputs of the stress-test. This provides a tool to challenge and enhance our understanding of portfolio behaviour in extreme scenarios, not a solution.

People in this country have had enough of experts

UK politician Michael Gove, June 2016
Blending expert opinion with quantitative analysis

In the previous section, we stated that the risk team combines the forecasts of our investment experts under different scenarios into a model to stress-test portfolios. In this section, we consider the considerable challenge of putting this into practice.

Combining subjective views into a risk model is one of the main challenges of quantitative portfolio management. The information provided by our investment experts needs to be incorporated in a statistically sound way. The mainstream approach to performing this task uses the Black-Litterman model (1990). However, this assumes that the distribution of risk factors is normal. It therefore fails to describe the expected distribution of returns. That is, it does not capture the fat tails, those extreme market moves that occur far more regularly than predicted under a normal distribution.

The mathematical concept behind the approach we employ is maximum entropy. It produces a distribution that is consistent with the inputs in a way that imposes the least possible spurious structure.

For decades, the principle of maximum entropy has been used in the world of physics for a wide range of applications, from statistical mechanics to information theory and logical inference. The introduction of entropy maximisation in the context of stress testing and scenario analysis is relatively recent, with the global financial crisis providing the spur for better understanding of financial risk. The mathematics is described in more details on the next page.

Maximum entropy, minimum hubris

From a practical perspective, what does this approach achieve?

For portfolio managers, it describes the expected behaviour when the unexpected happens. In particular, it allows them to identify any unintended concentration risks in the portfolio.

It incorporates both historic data and the forecasts of our investment experts for the stress scenarios identified. It does this in a way that is mathematically valid. This captures the fact that markets move across a wide and diverse range of volatility and correlation regimes. In this way, it avoids the problem of models with static correlation matrices, which break down in a crisis.

It takes account of the fact that the combination of history and the specified stress scenarios does not capture all possible scenarios. It recognises that more things can happen than have happened or will happen. This is achieved through the creation of a library of thousands of possible histories that are statistically consistent with history. It is a practical solution to the fact that there are few data points in a crisis environment. It produces an appropriate distribution of returns and correlations that can be used in risk management and portfolio optimisation.

Maximum entropy is a mathematical approach to ensure maximum humility in our ability to forecast the future.

**Measurement is not an alternative to judgement:** measurement demands judgement: judgement about whether to measure, what to measure, how to evaluate the significance of what’s been measured, whether rewards and penalties will be attached to the results, and to whom to make the measurements available.

*The Tyranny of Metrics, Professor Jerry Muller*
Maximising entropy

The principle of maximum entropy was first introduced by the physicist E. T. Jaynes in 1957. It has since been used in a wide range of areas including statistical mechanics, information theory, and logical inference. The use of entropy maximisation in the context of scenario analysis is relatively recent, and is due to Meucci (2008). It also underpins the Consistent Information Multivariate Density Optimizing methodology as described by Segoviano (2006) at the IMF.

For our purposes, we can efficiently implement the problem of maximising entropy with constraints in standard mathematical optimisation packages. This maximisation leads to a unique solution, and the number of dimensions scales with the number of constraints and not the number of Monte Carlo samples, making the approach scalable. Following Meucci, we will call this approach the Entropy Pooling methodology.

It is important to realise that the concept of entropy does not arise arbitrarily in this context, but is necessary if we want to derive a forward-looking distribution that does not contain any more information than the prior and the expert views. It is also, for our purposes, compatible with standard Bayesian inference. For more details on this point, please refer to Giffin (2008) and the appendix. Given the natural way in which entropy maximisation arises, it is perhaps not surprising that in a simple world in which returns follow a single multivariate normal distribution this approach leads to the Black-Litterman solution. However, for a multi-regime model encoded as a library of Monte Carlo simulations, much richer scenarios can be created. In addition, it is possible to accommodate more complex views than is possible in the Black-Litterman framework.
The changing relationship of US equity and US credit returns

Chart 3 shows the relationship between US equity and credit returns through the market cycle. It maps a scatter-plot of weekly returns of the S&P 500 Total Return Index on the x-axis against weekly returns of the Merrill Lynch Corporate Master Index on the y-axis over a 17-year period. In addition, we show the outline of a single multivariate normal distribution that has been calibrated using the entire data set.

The chart clearly shows that use of a single distribution does not capture the tail dependence of these two return series. So, while the average correlation of just -0.04 suggests bonds and equities do not move together, experience tells us that during extreme falls (such as happened in 2008), they in fact tend to behave in unison. As with the US equity example in Chart 2, we obtain a much better fit to the actual data when we employ a multi-regime model – that is to say, we recognise that the relationship between equity and credit returns changes throughout the market cycle.

Chart 4 shows the library of simulated annualised returns (using Monte Carlo techniques) that incorporates the various correlation structures observed during the same 17-year period, based on a large number of different regimes. This distribution retains the tail-dependence observed in the historical data and cannot be parameterised by a single distribution.

We now consider a ‘credit collapse’ scenario – our expert opinion has defined this as a -20% shock to the credit index. The prior belief (fuzzy picture) has to be updated in light of this new information using the entropy pooling methodology (see Chart 5).

Practically, we can achieve our objective by re-weighting the simulations in our library, such that the average loss for the credit position is -20%. In Chart 5, a -20% shock to the credit index is used to infer a drop in the equity index. The methodology correctly infers that, for extreme shocks such as a -20% drawdown in the credit index, the co-dependence between equity and credit is much stronger than for ‘normal’ periods; the expected loss for the equity position under this methodology is also about -20%. This contrasts markedly with a traditional ‘single state’ approach where a -20% shock in the credit return would imply a +3% rise in the equity index.

Chart 3: Equity returns versus credit returns using a single-state distribution

![Chart 3: Equity returns versus credit returns using a single-state distribution](image)

Source: Bloomberg, authors’ computation, calibrated with reference to market data
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Chart 4: Equity versus credit return simulation using a multi-state model

Source: Bloomberg, authors' computation using a multi-state model, calibrated with reference to market data

Chart 5: Simulated equity versus credit returns under a 'credit collapse' scenario

Source: Bloomberg, authors' computation using a multi-state model, calibrated with reference to market data
The methodology we demonstrated can be applied to a wide range of asset classes whose returns we can model, and to a specific set of expert opinions about unlikely events.

For the purpose of the next set of analyses, we used the asset weightings of a typical US institutional strategic asset allocation to test its robustness against a scenario we define as ‘China crisis’. Our understanding of this strategic asset allocation is based on two annual pension fund surveys (Wilshire and NASRA) that compute average asset allocations across a somewhat homogeneous group of plans, state retirement pension funds.

China crisis – key assumptions

• Economic rebalancing causes China’s growth to slow significantly.
• The slowdown is compounded by rising inflation/wages.
• Demographics limit future development.
• The economy is further hampered by the debt-fuelled investment boom/misallocation of resources/debt quality.
• Productivity growth remains low or falls further.

China crisis – key expert inputs

| US$ vs AUS$ | +15.0% |
| Hang Seng Index | -60.0% |
| US 10-yr Treasury yield | -0.75% |
| German 10-yr bond yield | -0.25% |
| CDX IG spread | +1% |

Treatment of liquid and illiquid asset groups

By using a typical US institutional strategic asset allocation, we can derive a sense of its likely behaviour given this information. Although modelling liquid assets (i.e. where we have daily data) is straightforward, more thought is required for how to treat less liquid investments such as private equity and real estate. While price direction will ultimately be the same as for liquid equivalents, the less frequent pricing of these assets will typically create time delays in their behaviour in tail-risk events.

We have taken the most optimistic approach here and treated less liquid investments as static in nature. That is, we assume their prices remain the same and that in such a crisis, these assets become effectively untradeable. Modelling these assets as their liquid equivalents (such as public equity for private equity and REITs for real estate) would cause materially worse outcomes in tail-risk modelling. As it is, memories of the 2008 global financial crisis and the resultant distortions on the typical US institutional strategic asset allocation weightings should provide a recent reminder of the downside risks of the illiquidity premium.
Output analysis

The changing relationship of US equity and US credit returns

Chart 6 shows the likely negative impacts of a China crisis on various asset classes. Unsurprisingly, equities suffer significantly, while fixed income provides some protection, albeit returns are still negative. For ‘alternatives,’ we have considered only the liquid portion of this allocation, i.e. hedge portfolios. We can see that, as a universe, these portfolios have provided limited downside protection. However, we appreciate that in practice there will have been a wide dispersion of returns around this central figure, dependent upon manager and strategy selection.

To calculate the expected losses for the typical US institutional strategic asset allocation, we use the following weighting assumptions.

For modelling purposes, given the earlier assumptions on illiquid assets, we are effectively looking at asset movements on 90% of the portfolio (10% of the portfolio being illiquid assets, global real estate and private equity).

Combining the return forecasts (see Chart 6) with the asset weightings produces an expected negative total return of -15.4% for the entire portfolio (the sum of the contributions in Chart 7).

Unsurprisingly, given the large bias toward the domestic equity market, the losses are greatest here. As pointed out earlier, using liquid market assumptions for some of the illiquid portfolio components would lead to significantly worse outcomes for the portfolio.

While fixed income suffers considerably less than equities in this extreme scenario, it is still negatively impacted. Moreover, it offers limited long-term returns, especially with prevailing fixed-income yields expected to rise in many developed markets. As discussed earlier, while hedge portfolios as an overall investment group can give good protection, their well-documented shortcomings (high fees, selective access, disclosure opacity, indifferent performance) may preclude greater allocations to this asset class group in its own right.

Weighting assumptions

<table>
<thead>
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<th>Asset Class</th>
<th>Weightage</th>
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</thead>
<tbody>
<tr>
<td>US Equities</td>
<td>30%</td>
</tr>
<tr>
<td>US Corporate Bonds</td>
<td>30%</td>
</tr>
<tr>
<td>Global Equities</td>
<td>20%</td>
</tr>
<tr>
<td>Global Real Estate</td>
<td>5%</td>
</tr>
<tr>
<td>Alternatives - Hedge portfolios</td>
<td>5%</td>
</tr>
<tr>
<td>US High Yield Fixed Income</td>
<td>5%</td>
</tr>
<tr>
<td>Alternatives – Private Equity</td>
<td>5%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Bloomberg, authors’ computation at 29 December 2017
The emergence of absolute return portfolios as a mainstream global investment has been partly driven by a desire for the strong diversification benefits that hedge portfolios can offer but without the traditional drawbacks.

For the next part of the paper, we consider a representative absolute return portfolio, where we have the transparency of underlying investment positions. This lets us see how future scenario analysis might help portfolio managers understand the likely behaviour of their holdings in extreme market conditions.

By way of a brief introduction, the multi-asset absolute return portfolio under analysis consists of a diverse range of investment positions (long and relative value in nature) in traditional markets and in selective currency, interest rate and volatility markets. All portfolio positions are extremely liquid, hence ideal for this type of analysis.

The investment objective of this multi-asset portfolio is to deliver an absolute return of cash +5% per year, gross of fees (i.e. consistent with the long-term return on equities), irrespective of market conditions, over a rolling three-year period with volatility expected to be less than half that of a traditional equity portfolio.

Because of the absolute return nature of this portfolio, studying its potential behaviour in extreme scenarios is a core element of the investment approach.

Performing the China crisis scenario analysis, the absolute return portfolio in this case would deliver a return of -7.4%. This compares favourably with global equities (-31%, Chart 6).

The multi-asset absolute return portfolio in this analysis has around 30 return-seeking positions at any time, both long and relative value, invested across geographies and asset classes. Thus, it seeks to hold a very diverse set of investment risks. Chart 8 shows the contributions to return of the constituents of the multi-asset absolute return portfolio in the China crisis scenario.

As can be observed, carefully selected investment strategies in currencies, volatility and relative value equity, which are chosen in the belief they can make money in normal market conditions, can also provide good returns in the China crisis scenario. Such strategies can thereby offset losses in more traditional return-seeking strategies.

The elegance of forward-looking scenario analysis allows for the specification of many additional unlikely but plausible ‘bad outcomes’ for markets. This involves little extra work except for the actual specification, which is thereby the most important input of any given scenario.
Chart 8: Absolute return portfolio constituent breakdown in China crisis totalling -7.5%

Source: Bloomberg, authors’ computation at 29 December 2017
Organisation challenges for constructing extreme scenarios

However mathematically pleasing this analysis is, it constitutes only a small (albeit crucial) aspect of scenario analysis. It must be remembered that the output is just a robust mathematical articulation of expert opinion and that the expert opinion may itself be deeply flawed.

Put more simply, garbage in, beautifully modelled garbage out.

It is important to recognise that the value of successful scenario analysis should not lie in the exact specification of portfolio gains and losses in a specific scenario – the results should be intuitively correct but not spuriously accurate. Rather, its benefits lie in the process and interaction it enforces.

Ultimately, forward-looking scenario analysis is a tool to explore potential portfolio weaknesses, through the interactions of:

- experts, who specify scenario shocks
- risk managers, who model the inferred losses
- portfolio managers, who can use the results to challenge and enhance their intuitive understanding of the behaviour of their portfolios in extreme scenarios.
Conclusion

In this paper, we have demonstrated a methodology to quantitatively translate expert opinion about future world states into portfolio outcomes.

Furthermore, we have shown how using an absolute return investment approach can be beneficial in helping mitigate losses in such extreme markets.

Finally, we highlight that the real value of such analysis is in the engagement of portfolio managers in the scoping and output of the work, allowing them the opportunity to improve current portfolio construction techniques.

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References

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