MSCI Barra RESEARCH INSIGHTS

The Long View of Financial Risk

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[Leading up to the credit crisis, financial models took a] view of the world that was far more benign than it was reasonable to take, emphasizing recent inputs over more historic numbers. – Myron Scholes, quoted in "Efficiency and Beyond," The Economist, 16 July 2009

Even the tamest financial markets can produce unpredictably wild return dynamics. Low volatility regimes are punctuated with extreme events, and interspersed with bursts of turbulence that differ in magnitude, duration and other details. Figure 1 shows a history of daily returns to the MSCI USA Index. The highlighted region marks the four years preceding the credit crisis (June 2003—May 2007). This limited window exhibits tractable dynamics that may be amenable to very simple statistics (such as Gaussian). But the long view shows less regularity and a wider range of behavior. This irregularity is also seen in how prices move together. Figure 2 shows contemporaneous daily returns to Coca-Cola and Exxon-Mobil over different periods. These plots show that assets that appear uncorrelated, even for a long time, can suddenly become highly correlated. Calm periods can persist for years, so a deep historical perspective is required to appreciate the market's potential for surprise.

Figure 1: Daily returns to the MSCI USA Index; highlighted time-span is four years prior to the credit crisis (June 2003—May 2007).

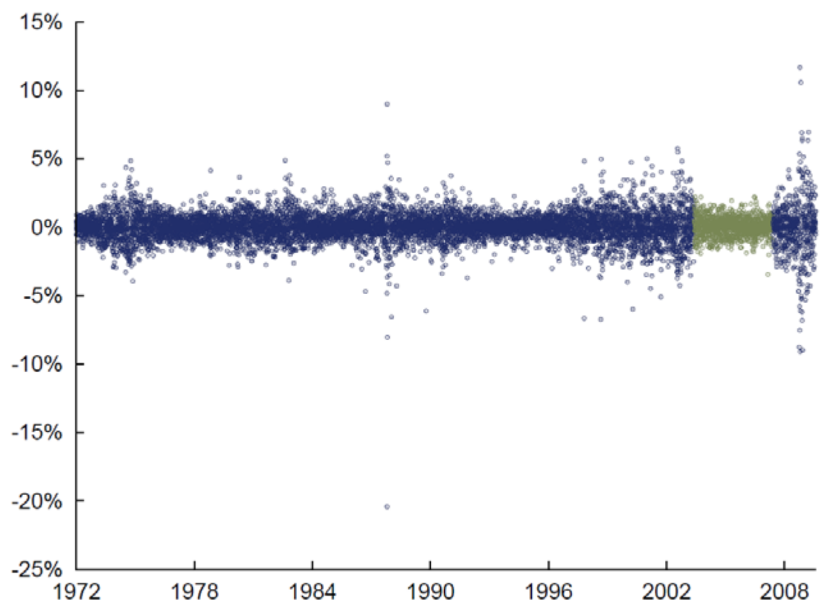

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Figure 2: Contemporaneous daily returns to Coca-Cola (horizontal axis) and Exxon-Mobil (vertical axis) in four-year snapshots (1981—present).

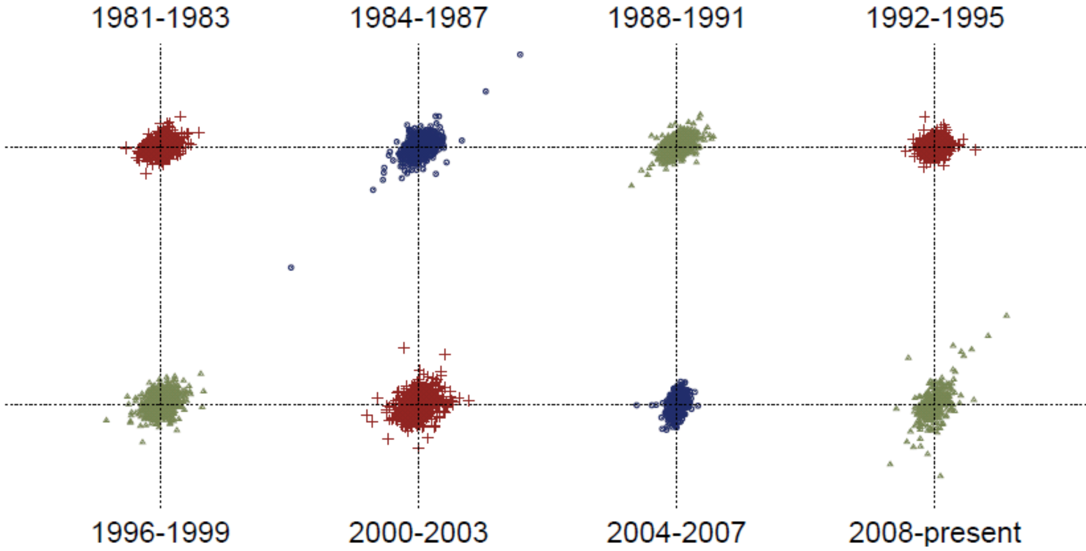
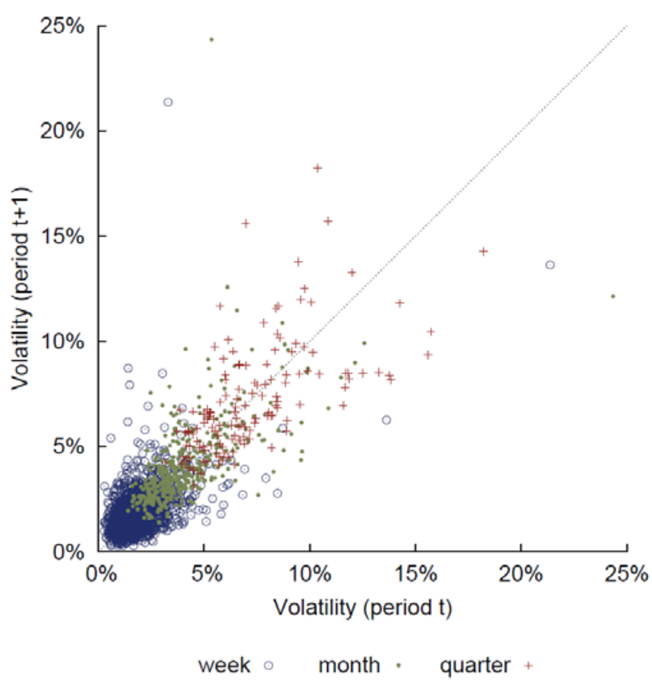


Figure 3: Realized volatility of the MSCI USA Index in adjacent 1-week, 1-month, and 3-month periods, estimated with daily returns and neglecting autocorrelation.



Nonetheless, the practice of quantitative risk management is typically not informed by a long view of history. The most enduring application of statistics to risk management is forecasting *variance* (or its square root, *volatility*). One reason for this is that variance shows uncommon predictability across consecutive periods. Figure 3 shows realized volatility on adjacent periods over the history of the MSCI USA Index. The straight-line relationship implies that tomorrow's variance is largely an echo of today's variance.

Figure 3 further suggests that recent history may be the best guide to forecasting variance, and indeed variance is most commonly measured using a short history. For daily variance, a common choice is exponential weighting of the history, with a half-life of around 23 days. This means that data from the past 6 months almost completely determine tomorrow's variance forecast, so variance is not ideally suited to take full advantage of a deep data history. Variance also penalizes gains and losses equally, which unfairly characterizes the risk of bets with large upside. For example, the risk of a long position in an out-of-the-money put is largely upside risk.

Every economic crisis provides fresh motivation to improve the practice of quantitative risk management. Some recent efforts include Bouchaud (2008), Bhansali (2008), and Sheikh and Qiao (2009). Guiding theoretical work abounds in the academic literature; see, for example, Artzner et al. (1999), Rockafellar and Uryasev (2000), Carr et al. (2001), Uryasev (2002), Föllmer and Scheid (2002), Föllmer and Scheid (2004), Bertsimas et al. (2004), Rockafellar et al. (2006), Rockafellar et al. (2007), Cherny and Madan (2007), and references therein. Some of this content has recently been codified in a practitioner-oriented framework in Goldberg et al. (2009).

This paper focuses its efforts to this end on developing a risk measure that harnesses market history, while retaining variance's intuitive, predictable, and useful properties. In the following sections we review the basic properties that make variance useful, and describe their economic and practical implications. We then present a candidate risk measure, *shortfall*, which shares key properties with variance, while taking advantage of a long history and addressing a different facet of risk. We conclude with a list of questions for future research.

1. What Makes a Good Risk Measure?

In a landmark paper, Markowitz (1952) mathematically formulated portfolio construction as a tradeoff between expected return (desirable) and risk (to be avoided). Markowitz proposed variance to measure risk, but repeatedly emphasized the broader goal of seeking and measuring diversification:

Diversification is both observed and sensible; a rule of behavior which does not imply the superiority of diversification must be rejected.

Since Markowitz, many alternatives to variance have been suggested. Some early examples are semi-variance (or downside variance), higher moments (skewness), and more recently Value at Risk. A drawback to all of these examples is that they do not consistently reward diversification. A related consequence is that these risk measures are difficult or impossible to optimize.

More recently a series of academic papers have addressed the question of what makes a good risk measure; see for example Artzner et al. (1999), Föllmer and Scheid (2002), Föllmer and Scheid (2004, Chapter 4), Rockafellar et al. (2006) and references therein. While there is not a consensus on all details, every response echoes Markowitz by demanding that a "good" risk measure promote diversification. This condition is guaranteed by the mathematical property of *convexity*. Recently proposed convex risk measures include shortfall, acceptability indices, MinMaxVaR, and MaxMinVaR. Further details are in Eberlein and Madan (2007), Cherny and Madan (2006) and elsewhere.

Convexity can be visualized in terms of a curve that represents portfolio risk as a function of relative asset weight. If the risk measure is convex, a straight line between any two points on the curve will lie on or above the curve. Convexity is guaranteed (in one dimension) by a non-decreasing slope (first derivative), when it exists. This means that as the weight in any position increases, the slope of portfolio risk also increases (or stays flat), but cannot decrease. Some convex and non-convex curves are sketched in Figure 4. A hint of variance's elegant generality is revealed in the top left-hand curve in Figure 4, which depicts the shape of *every* asset's variance profile. The only parameter is the ratio of height to width of the curve.

Figure 4: Left: Convex curves, Right: non-convex curves

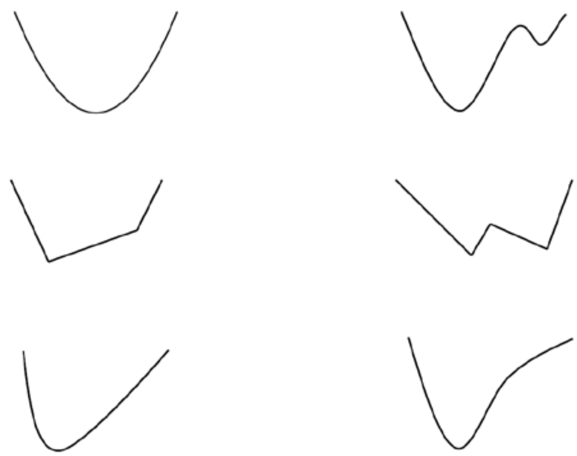


Figure 4 illustrates the connection between convexity and diversification: the risk of any combination of two assets (intermediate points) will never be greater than their average stand-alone risks (straight line). Artzner et al. (1999) make the incisive point[2] that *[Diversification] does not create extra risk.*

If a diversified portfolio had greater risk than the average stand-alone risks, this would imply that diversification was intrinsically risky. Consider the extreme case when two assets are exact duplicates (perfectly correlated, statistically identical). Convexity allows the diversified risk to equal the average stand-alone risks, but not exceed it. Non-convexity admits the possibility that the act of putting two assets together into a portfolio entails its own risk, so non-convex risk measures may encourage concentration over diversification.

More generally, consider a decomposition of a portfolio return into weighted return of its n components[3]:

$$P = \sum_{i=1}^{n} x_i A_i . \tag{1}$$

Here x_i denotes the weight of component i, and A_i denotes the return. A measure μ of the risk of P is *convex* if

[2]Artzner et al. (1999) were referring to the property of *subadditivity*, but their insight applies equally well to convexity.
[3] Change in portfolio value over an investment period can also be expressed in units of profit and loss. This is more general, since it allows for any starting value. However, units of return are generally preferred for long-only portfolios and those with relatively low leverage.

$$\mu\left(\sum_{i=1}^{n} x_i A_i\right) \leq \sum_{i=1}^{n} x_i \mu(A_i) \quad (2)$$

if $\sum_i x_i = 1$ and $x_i \geq 0$. Paraphrasing the succinct statement of Föllmer and Scheid (2004, Page 154):

If one diversifies, spending only the fraction x_i on component A_i, one obtains $\sum_{i=i}^{n} x_i A_i$. Thus, convexity gives a precise meaning to the idea that diversification should not increase risk.

2. Managing Convex Risk

The slope of the risk profile (Figure 4) is referred to in risk management as the *marginal contribution to risk (MCR)*:

$$\mathrm{MCR}^{\mu}(P, A_i) := \frac{\partial \mu(P)}{\partial x_i}, \quad (3)$$

MCR describes the impact of a relatively small trade on portfolio risk. By examining the marginal contributions across a collection of assets, sectors, or factors, an investor can determine the set of trades that have the greatest impact on portfolio risk.

One important consequence of convexity is that following the gradient (slope in more than one dimension) downward will always lead to the global minimum risk portfolio. This property gives the gradient of a convex risk measure special utility to investors seeking to optimize risk. In contrast, a non-convex measure may have multiple minima, so a particular minimum risk portfolio is not guaranteed to be the global minimum. Consequently, following the gradient of a non-convex measure may lead away from the global minimum.

Marginal contribution to risk can be used to study the implied return of assets through *reverse optimization* (see e.g. Sharpe (2001)). Consider an unconstrained portfolio that is optimal with respect to a particular risk measure, meaning

$$f(\mathbf{x}) = \mathbf{E}[\mathbf{x} \cdot \mathbf{A}] - \varrho \mu(\mathbf{x} \cdot \mathbf{A}) \quad (4)$$

is maximized (• is a risk aversion parameter). If *f* is maximized, its derivative with respect to all weights is zero:

$$\frac{\partial f}{\partial x_i} = \mathbf{E}[A_i] - \varrho \mathrm{MCR}^{\mu}(P, A_i) = 0 \quad (5)$$

so the expected return of an asset is proportional to its MCR. Reverse optimization thereby provides a prescription for how much return should be demanded of an asset to compensate for its risk, and may reveal unintended bets.

Since the slope of a convex curve is non-decreasing, selling an asset decreases the MCR of a convex risk measure, and buying an asset increases its MCR. If the expected return implied by the current holdings is incompatible with an investor's views, selling an asset reflects a more bearish view (lower implied return), whereas buying an asset reflects a more bullish view (higher implied return). For non-convex measures, this basic investment intuition may be violated: one may be moved to sell an asset to increase its implied return.

For convex risk measures, the marginal contribution is bounded by the stand-alone risk of an asset. In some contexts it may be useful to explicitly consider these bounds, as they define the bounds on expected return in *any* portfolio through reverse optimization.

The marginal contribution to a convex risk measure can be decomposed as:

$$\mathrm{MCR}^{\mu}(P, A_i) = \rho^{\mu}(P, A_i)\mu(A_i). \quad (6)$$

Here ρ^{μ} is a generalized correlation (Goldberg et al. (2009)) that reduces to standard (volatility-implied) correlation if μ is volatility (Menchero and Poduri (2008)). It is non-decreasing for convex measures, so the correlation of an asset with a portfolio never decreases upon adding weight in that asset.

3. The Special Case of Shortfall

Shortfall (s) is the average loss beyond a given (high) percentile of possible losses, so it is an estimate of an especially severe loss. The level of severity is specified by the percentile. Shortfall is also known as *Expected Shortfall*, *Conditional Value at Risk*, *Average Value at Risk*, and *Expected Tail Loss*. As an average over the worst outcomes, shortfall is a guide to capital reserve allocation and risk monitoring. Shortfall provides a forecast of those extreme losses that capital reserves are designed to cover.

Since it is a convex measure of risk, shortfall, like volatility, promotes diversification and is a sensible optimization constraint. Unlike volatility, which is most accurately estimated using recent history, high percentiles of shortfall demand abundant data to obtain reasonable estimation error (see Yamai and Yoshiba (2002)). Finding adequate data is a significant challenge to applying shortfall in practice. Asset-level returns may not be uniformly available for long periods, so a factor-based approach to estimation may be more practical in some situations. Short-term risk is most accessible, because there are more (non-overlapping) historical returns at shorter horizons. A framework for extracting consistent long-view statistics from factor history is developed in Goldberg et al. (2008) and implemented in the Barra Extreme Risk (BXR) Model, which currently forecasts risk on horizons of one to ten days.

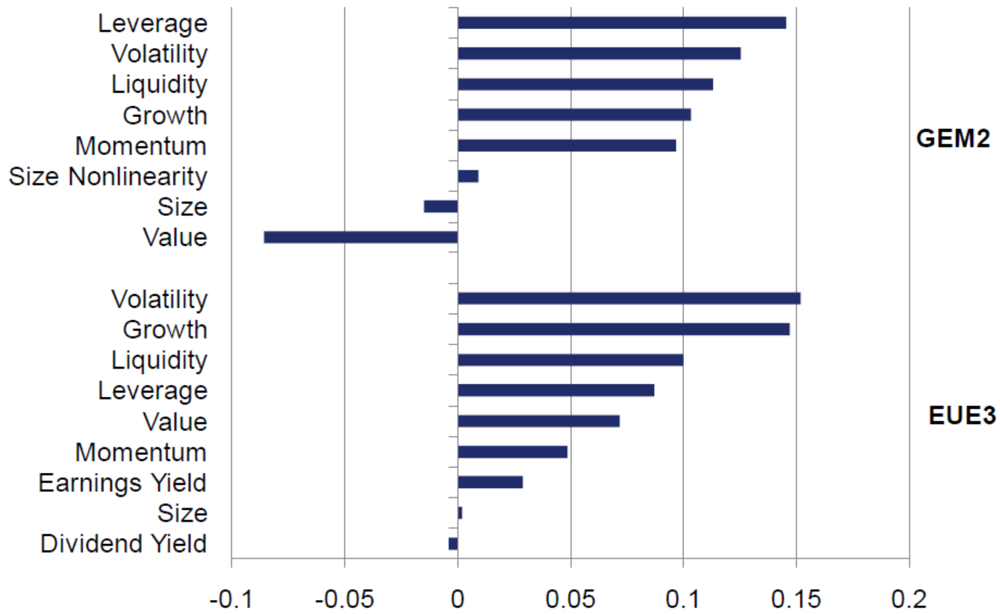
Using out-of-sample tests over a period of 11 years (1996—2007) Barbieri et al. (2008) show that BXR outperforms a conditionally normal model, which takes shortfall to be a fixed multiple of volatility. This suggests that a long, consistently applied history provides a more accurate forecast of extreme risk than a short history.

Forecasts of shortfall in BXR are called *Extreme Shortfall* or *xShortfall*, and they can be written as a time-dependent volatility term multiplied by a time-independent constant ($s_t=\sigma_t C$). Estimates of time-independent constant C change as new information becomes available, but are stable when estimated with a long history. A measure NN of non-normality is the ratio of C to the corresponding constant in a Gaussian model (C^G) minus one:

$$\mathrm{NN} = \frac{C}{C^G} - 1$$

The quantity NN is the fractional difference between xShortfall and a Gaussian shortfall estimate. Figure 5 shows values of NN for style factors in two Barra factor models: Global Equity Model (GEM2) and Europe Equity Model (EUE3). The values were computed on 30 December 2008 using 12 years (GEM2) and 14 years (EUE3) of daily factor history. Protective factors such as Size in both models, and Value in GEM2 appear less risky than normal, while aggressive factors such as Leverage, Growth, and Momentum appear riskier than normal. This result may be familiar to a veteran of financial markets, as it reflects empirical factor behavior across history.

Figure 5: Non-normality (NN) of 95% 1-day shortfall of style factors in two Barra factor models: Global Equity Model 2 (GEM2) and European Equity Model 3 (EUE3). The non-normality measure displayed is the percent difference between normal and Barra Extreme Risk estimates of 95% 1-day shortfall.



Marginal contributions to shortfall admit to a simple and testable formulation. Under mild assumptions on the distribution of portfolio return,

$$\begin{aligned} \mathrm{MCR}^s(P, A_i) &= \frac{\partial s(P)}{\partial x_i} \\ &= E[A_i \mid P > \mathrm{VaR}]. \end{aligned} \tag{7}$$

In other words, the marginal contribution to shortfall is equal to the expected return of asset *i* when the portfolio Value at Risk is exceeded. MCR^S describes the behavior of assets when the portfolio suffers large losses, revealing which assets can be expected to mitigate a large loss.

Test statistics that evaluate the accuracy of shortfall are developed in Goldberg et al. (2008), Watewai (2007) and Barbieri et al. (2008). These statistics compare forecast shortfall to realized loss (–*P*) when a Value-at-Risk limit is exceeded. They are averages of ratios (realized to forecast) or differences (realized minus forecast). Using Formula (7), we can construct statistics to test marginal contributions of assets, sectors and factors to shortfall. Further out-of-sample evaluation of shortfall and marginal contributions to shortfall for diverse classes of portfolios over different market climates and time horizons is required to assess the value of shortfall forecasts to investors.

The long view of history in BXR provides insight into extreme market dynamics, accounting for volatility uncertainty, sudden spikes in correlation, frequent outliers, and asymmetry between gains and losses. Out-of-sample results raise the possibility that financial extremes are, to some extent, predictable. *Importantly, they are intrinsically less predictable than volatility.* Nevertheless, the inclusion of shortfall in the portfolio construction process may lead to better performance, as shortfall addresses an aspect of risk and a source of data that are outside the purview of volatility.

4. Suggestions for Empirical Studies

Although shortfall represents a significant advance in our understanding of financial risk, it is certainly not the endgame. New sources of data will reveal new opportunities for empirical risk management, allowing refinements of old statistics or the estimation of new ones. Creative application of the theory of convex risk may lead to even more relevant and useful measures. On this theme of the future of risk management, we provide a list of empirical questions for future research.

What is the impact of leverage on risk?

In the concluding remarks to his analysis of the Long-Term Capital Management (LTCM) investment strategies, Jorion (2000) comments:

... such [undiversified and highly leveraged] *strategies are fundamentally dangerous and much riskier than measured by traditional risk management systems.*

Leverage scales the range of portfolio outcomes without changing the initial investment. The scale factor or *leverage ratio* (λ) in a portfolio is the amount invested divided by initial capital. In an influential article, Artzner et al. (1999) propose that risk depends linearly on leverage:

$$\mu(\lambda P) = \lambda\mu(P), \quad \lambda > 0. \tag{8}$$

While there are theoretical benefits to linear scaling, such as the Euler decomposition of risk into sources (described in Goldberg et al. (2009) and elsewhere), it is not clear that Formula (8) is flexible enough to measure the real impact of leverage on risk. Linear scaling implies that investing $100 of capital in a stock is only half as risky as borrowing an additional $100 to invest a total of $200 in the same stock. In the first investment, the most you can lose is your entire stake of $100. In the second, you stand to lose double your initial investment, and you are at the mercy of the market. It may be disadvantageous, or even impossible, to borrow what you owe.

Volatility and shortfall satisfy the linear scaling property in Formula (8). Therefore, even in combination, they may not fully describe the risk of leverage in a portfolio. All convex risk measures satisfy a less restrictive leverage rule (as long as the risk of a constant-valued portfolio is zero):

$$\begin{aligned} \mu(\lambda P) &\geq \lambda\mu(P), \quad \lambda \geq 1 \\ \mu(\lambda P) &\leq \lambda\mu(P), \quad 0 \leq \lambda \leq 1. \end{aligned} \tag{9}$$

Föllmer and Scheid (2004, Chapter 4) analyze convex measures that do not scale linearly, such as the minimum entropy risk measure, given by $\log \mathbf{E}[e^{P}]$. LTCM reported their risk as comparable to that of the S&P 500; a convex risk measure that scales nonlinearly could alert investors to the hidden impact of leverage.

Is there a shortfall risk premium?

The capital asset pricing model assumes that the market prices assets by compensating only for their volatility risk. According to Fama and French (2004), most explanations for departure from the CAPM are of two types. The first is that equity indices and other proxies for the market portfolio used in empirical studies are not sufficiently representative. In other words, studies that purport to test the CAPM are, in fact, testing something else. The second type of explanation focuses on the simplifying assumptions underlying the CAPM, such as a consensus view of asset means and variances, market equilibrium, and absence of constraints (see, for example, Markowitz (2005)). Fama and French point out that the empirical departure from the CAPM calls into question many of its textbook applications.

It is conceivable that markets demand a shortfall risk premium in certain climates. This raises the possibility that the market portfolio may sometimes be closer to mean-shortfall efficient than to mean-variance efficient. Or perhaps the market is efficient with respect to a convex risk measure that is sensitive to leverage. Tests described in Fama and French (2004) can be applied to analyze these questions. If there is a shortfall risk premium, accounting for it could lead to a better asset pricing model.

Is portfolio insurance worth the price?

Lo (2008) posits a fictitious hedge fund in which the chief risk officer (CRO) implements a strategy to hedge downside risk exposure to collateralized debt obligations (CDO)s in a bull market.

From 2004 to 2006, such a hedging strategy would likely have yielded significant losses, and the reduction in earnings due to this hedge, coupled with the strong performance of the CDO business, would be sufficient grounds for dismissing the CRO.

To be of any use, out of the money puts and other forms of downside protection must be purchased before a crisis occurs. However, incentive structures throughout the financial services industry tend to be aligned with short term goals. The institution of less myopic incentives can be supported by empirical cost-benefit analysis of the value of downside protection. Since the results of any particular test depend on the details of the scenario used, it is desirable to consider the widest possible range of market conditions, asset classes, time horizons, investment strategies and insurance types.

5. Taking the Long View

Bender and Nielsen (2009) elaborate on three tenets of investing:

- Risk management is not limited to the risk manager. Anyone involved in the investment process ... should be thinking about risk.
- If you can't assess the risk of an asset, maybe you shouldn't invest in it.
- Proactive risk management is better than reactive risk management.

These common-sense principles are typical of the rhetoric that has accompanied the global market turmoil that began in 2007, but they are often ignored.

The empirically and scientifically motivated ideas reviewed in this article have the potential to support new financial markets that work better than the old ones. But they are no substitute for judgment, prudence, or an incentive structure that takes the long view.

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