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Cross Asset Research

Quantitative Portfolio Strategy
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The Effects of Volatility and Correlations on the Active risk of Equity Portfolios

- Equity portfolios can experience periods of lower tracking error volatility (TEV) than historical norms without any change in portfolio strategy. We develop a simple framework that illustrates how changes in equity volatilities, correlations and the number of stocks in a portfolio can affect its TEV.
- We test this framework against empirical data, using the SP500 index and five equally weighted 10-stock portfolios. We find that portfolio return volatility and TEV tend to be quite similar for our different portfolios and captured well by our simple model, even though their cumulative performance is strikingly different.
- We track how equity volatilities and correlations have changed over time and project the effect on portfolio TEV in the current environment. We find that for a 50-stock portfolio in which the bulk of the active risk is idiosyncratic in nature, the recent decrease in equity volatility would be expected to reduce TEV from 18 bp/day to 12 bp/day. To maintain TEV at the customary level of 18 bp/day in the lower-volatility environment would require a more concentrated portfolio of just 20 stocks.

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Effect of Volatility and Correlation on Active Risk

One of the key decisions facing an equity portfolio manager is the level of active risk (i.e., tracking error volatility) the portfolio should take relative to its benchmark. This is controlled by a combination of factors under a manager's control, such as the number and size of active positions, and some beyond it, such as the level of volatilities and correlations. To what extent can changes in market levels of volatilities and/or correlations among stocks affect the realized portfolio TEV?

To investigate this question, we develop a model for portfolio and benchmarck volatilities, and TEV under a very simple set of assumptions. We use the model to illustrate the type of relationship that can theoretically be expected to exist among single-stock volatility, average equity correlation, number of stocks in the portfolio, and TEV.

Next, we collect the return time series of the SP500 Index and 50 individual US stocks from among the largest constituents of this index. We use the observed volatilities and average correlations of these stocks to form estimates of the volatility and correlation parameters for our simple model. We also defined five equally weighted portfolios of 10 stocks each. Using the parameters estimated from these 50 stocks and a simple set of formulas, we form estimates of portfolio volatility, benchmark volatility, and TEV and compare these with the empirically observed values for these quantities. We find very good agreement in general; some specific discrepancies can be explained by sector allocations.

Finally, we return to our theoretical model armed with information on how equity market volatilities and correlations have changed over time and revisit the dependence of TEV on the number of stocks in the portfolio. We find that a 50-stock equity portfolio would be expected to have a TEV of about 18 bp/day if we use volatility and correlation figures consistent with long-term averages. However, using a lower volatility value consistent with 2014 experience, TEV would decline to about 12 bp/day for the 50-stock portfolio. Achieving a TEV in the range of 18 bp/day under the current lower-volatility environment would require a more concentrated portfolio of about 20 stocks.

A Simple Model for Portfolio Volatility and TEV

Assume a universe of stocks in which each stock has volatility σ. Further, assume that the benchmark is an equally weighted portfolio of *N* stocks, against which we are analyzing an equally weighted portfolio of *n* stocks selected from among those in the benchmark.

If we assume that all stock returns are uncorrelated, then it is straightforward to show that the return volatilities of the portfolio and the benchmark and the tracking error volatility (the standard deviation of the difference between the two) are given by:

$$\sigma_{portf} = \frac{\sigma}{\sqrt{n}}; \quad \sigma_{bmk} = \frac{\sigma}{\sqrt{N}}; \quad \sigma_{TE} = \sigma\sqrt{\frac{1}{n} - \frac{1}{N}}$$

At the limit, as *N* gets very large (and $N \gg n$), the benchmark volatility converges to zero, and the formula for TEV converges to being the same as the portfolio volatility.

In reality, of course, benchmark volatility is not zero. Stocks tend to move up and down as a group. This can be represented by the introduction of a market factor, or by removing our assumption that returns of different stocks are uncorrelated. If we now assume that the

returns of any two stocks are correlated by the same correlation coefficient ρ, we can show[1] that

$$\sigma_{portf} = \sigma\sqrt{\frac{1+\rho(n-1)}{n}}; \quad \sigma_{bmk} = \sigma\sqrt{\frac{1+\rho(N-1)}{N}}; \quad \sigma_{TE} = \sigma\sqrt{(1-\rho)\left(\frac{1}{n}-\frac{1}{N}\right)}$$

At the limit, as *N* gets very large (and $N \gg n$), these formulas converge to

$$\sigma_{bmk} = \sigma\sqrt{\rho}; \quad \sigma_{TE} = \sigma\sqrt{(1-\rho)\left(\frac{1}{n}\right)}$$

The limiting case, in particular, makes it clear that the effect of correlation on TEV works in the opposite directions for portfolio and benchmark risk. Increasing correlations increase overall portfolio and benchmark risk by reducing the diversification effect. However, the additional effect of increasing correlation is that the stocks in the portfolio will be highly correlated with the other stocks in the benchmark. This effect dominates, with the net effect that increasing correlation improves tracking and, hence, decreases TEV.

Testing the limits of these formulas by plugging in the extreme values for correlation gives intuitive results. If we push correlations to zero, we converge to our above results for the uncorrelated case. If we push correlations to 1, diversification is meaningless, as every stock will always earn the same return as any other. In this case, both the portfolio and benchmark return volatilities are just σ as for any single stock, and the TEV becomes zero, since the portfolio will perfectly track the benchmark.

Dependence of TEV on Number of Stocks, Volatility and Correlation

We now use the above formulas to illustrate the effects of changing volatilities and correlations at the portfolio level.

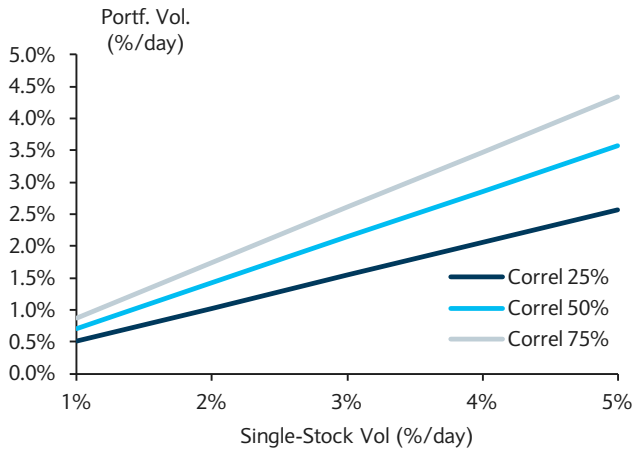
Figures 1 and 2 show that portfolio volatility and tracking error volatility increase linearly with single-stock volatility, as can also be seen in the formulas. However, the dependence on correlation works in the opposite direction: increasing correlation causes an increase in portfolio volatility (by reducing the effect of diversification) but a decrease in TEV (due to increased correlation between portfolio and benchmark returns).

Figures 3 and 4 show the effect of diversification: TEV can be seen as a decreasing function of the number of stocks, with a rapid decrease at first that slows down as the number of stocks grows. Figure 3 shows how this effect is modulated by changes in volatility under constant correlation, while Figure 4 shows how changing the correlation affects this function. Of the two parameters, TEV is more sensitive to volatility: changing our volatility assumption from 2%/day to 1% or 3% moves the curve by much more than changing the correlation assumption from 50% to 25% or 75%.

[1] The formula for portfolio return volatility can be found in Grinold and Kahn (2000), p. 48. The formula for tracking error volatility was developed in the context of corporate bond portfolios in Dynkin, Hyman and Konstantinovsky (2010), p. 19 but applies equally to equity portfolios.

FIGURE 1

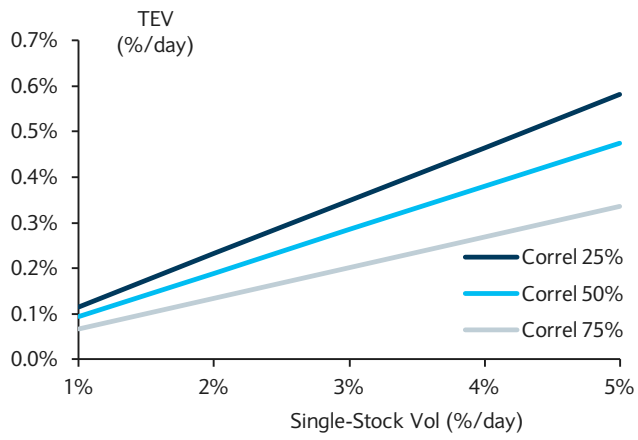
Volatility of a 50-stock portfolio, as a function of single-stock volatility and correlation



Source: Barclays Research

FIGURE 2

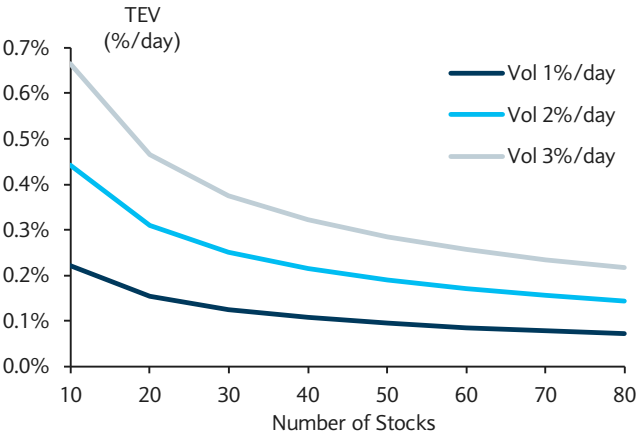
TEV of a 50-stock portfolio, as a function of single-stock volatility and correlation



Source: Barclays Research

FIGURE 3

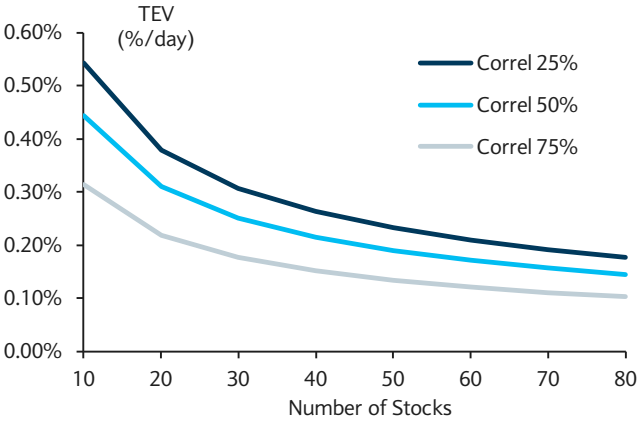
TEV as a function of the number of stocks in the portfolio and the single-security volatility, assuming constant 50% correlation



Source: Barclays Research

FIGURE 4

TEV as a function of number of stocks and correlation level, assuming constant 2%/day single-security volatility



Source: Barclays Research

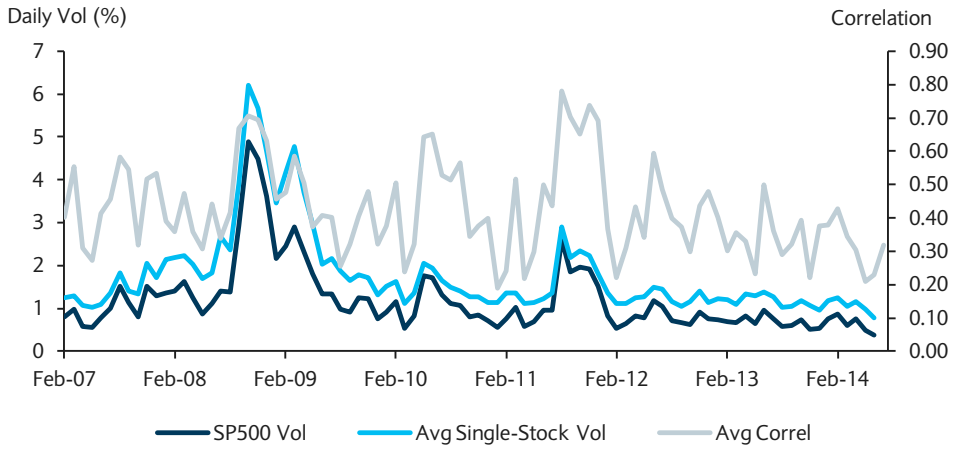
Empirical Results: Equity Volatilities, Correlations, and Model Fit

To represent the universe of U.S. large-cap equities, we use the SP500 Index. To estimate time series of the average single-stock volatility and the average correlation, we selected 50 of the largest stocks in the index[2] and lined up their daily historical total returns. We use a 30-day trailing window to estimate the volatility of each of our 50 selected stocks, as well as their pair-wise correlations. We then calculate the average volatility and the average correlation. We also measure the realized volatility of the SP500 index over the same 30-day trailing window. These statistics are plotted in Figure 5.

[2] We started with the composition of the index as of July 31, 2014, sorted by market capitalization, and selected from these the top 50 stocks that were also in the index as of the beginning of 2007. This introduces survivorship bias into our 50-stock sample, but this is not a major concern since our focus is on risk estimation, not performance.

FIGURE 5

Trailing 30-day volatility of SP500 Index, average volatility of 50 single-stock volatilities, and average pair-wise equity correlation



Source: Bloomberg, Barclays Research

Figure 5 suggests (based on both the index and the individual stock data) that volatility peaked in 2008, had another period of stress in 2011, and has been in decline since then. Correlations were less stable and tended to fluctuate throughout the period. There seems to have been a mild downward trend in correlations since the peak in 2011.

The formulas developed above, along with the estimates of single-stock volatilities and average pair-wise correlations among these 50 stocks, were used to estimate the volatilities of:

- Five equal-weighted portfolios of 10 stocks each
- The index
- The tracking errors between our portfolios and the index

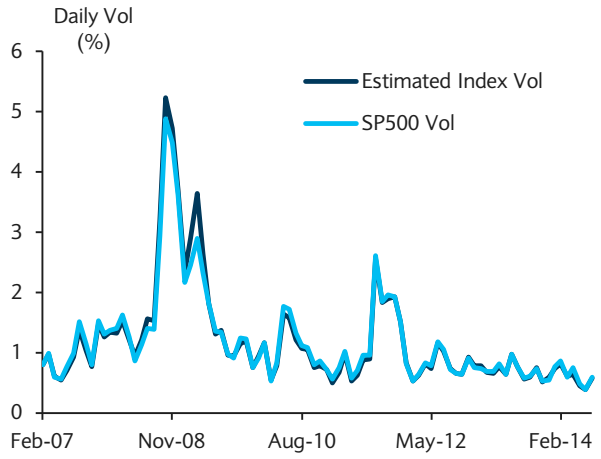
Figure 6 plots the realized volatility of the SP500 Index against the estimate obtained from the average volatilities and correlations of the largest 50 stocks. The chart indicates that the estimate tracks the actual index volatility almost perfectly throughout the period. Figure 7 displays the estimated volatility for an equal-weighted 10-stock portfolio based on our formulas against the observed volatility of the five portfolios we constructed. Over most of the period, all five portfolios follow the estimated value almost exactly. However, there are some deviations. Most notably, during the volatility spike of the crisis and recovery in 2008-09, Portfolio 1 has significantly higher volatility.

In Figure 8, we plot the estimated TEV of an equally weighted 10-stock portfolio against an equally weighted 500-stock index, based on the average single-stock volatilities and correlations, and compare this with the realized TEVs of our five portfolios against the SP500 index. Here again, the realized portfolio results tend to track the estimated values for most of the period, yet the deviations during 2008-09 are more pronounced, especially for Portfolio 1.

To understand the spike in volatility and TEV for Portfolio 1 during the crisis, note that these portfolios were not drawn at random, but were rather taken in order of market capitalization. The 343 stocks that have been in the index since the start of 2007 were ranked by their beginning market values, and the top 50 were selected to estimate our model parameters. The same 50 stocks were then partitioned by market value to form our five equally weighted portfolios. Thus, Portfolio 1 consists of the 10 largest stocks in this group as of the start of 2007, Portfolio 2 the 10 next largest, and so on. Of the 10 stocks in Portfolio 1, three of them (Citigroup, Bank of America, and AIG) were financials, giving this portfolio significant exposure to the financial industry just before its meltdown.

FIGURE 6

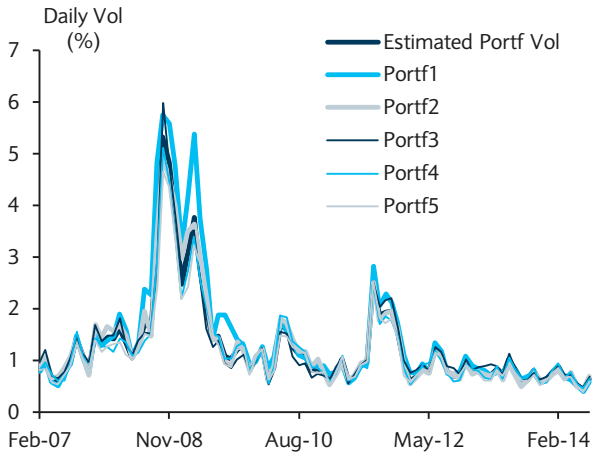
Estimated vs. realized volatility for the SP500 Index



Source: Bloomberg, Barclays Research

FIGURE 7

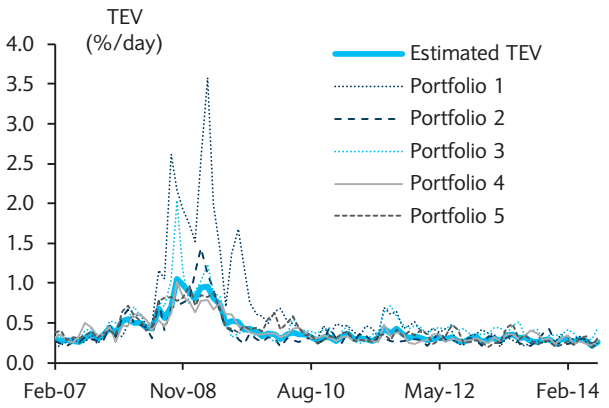
Estimated vs. realized volatility for five 10-stock portfolios



Source: Bloomberg, Barclays Research

FIGURE 8

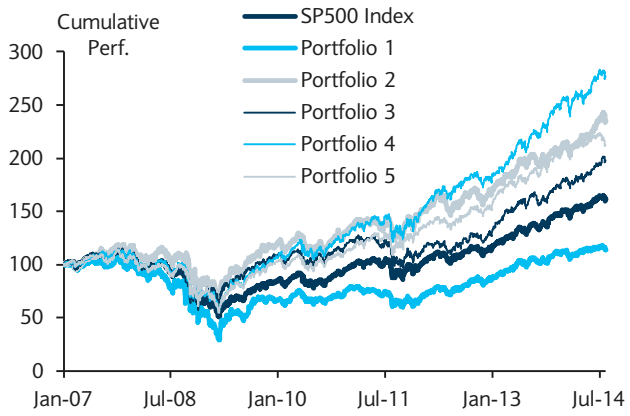
Estimated vs. realized tracking error volatility (TEV) for five 10-stock equally weighted portfolio vs. SP500 Index



Source: Bloomberg, Barclays Research

FIGURE 9

Cumulative performance of SP500 Index and five 10-stock equally weighted portfolios (31-Dec-2006 = 100)

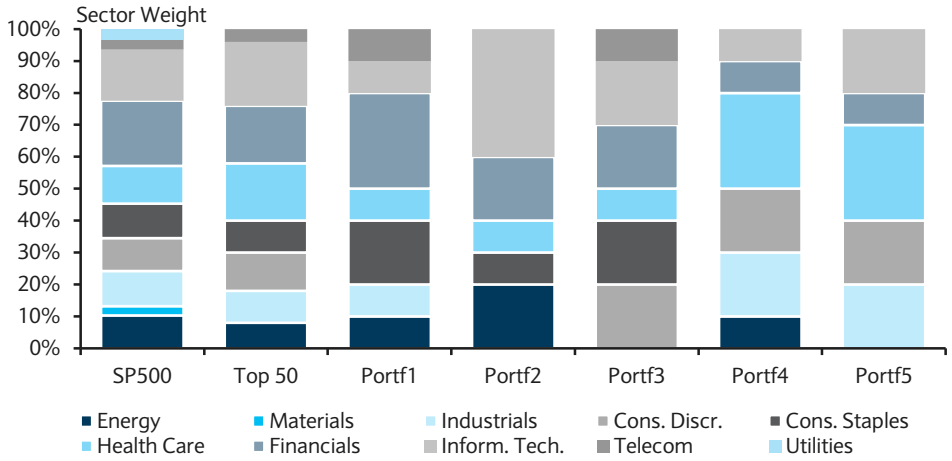


Source: Bloomberg, Barclays Research

Figure 9 shows the performance of the index and our five portfolios. Portfolio 1 significantly underperformed the index, earning an annualized return of just 1.70% from December 31, 2006, through July 31, 2014, vs. 6.42% for the index. The other portfolios outperformed the index, with returns over the period ranging from 9.40%/year for Portfolio 3 to 14.29% for Portfolio 4. There is a striking contrast between Figure 9, which emphasizes the differences in long-term performance among the five portfolios, and Figure 7, which shows how similar their behaviour is in terms of short-term volatility. This duality can be seen within Figure 9 itself. The performance charts for all of the portfolios diverge steadily over time, but their short-term fluctuations continue to mirror each other quite closely.

FIGURE 10

Sector composition of the selected index universe (by MV as of 31 December 2006), the (equally weighted) 50-stock calibration universe, and our five equally weighted 10-stock portfolios



Source: Compustat, Barclays Research

We suggested above that the elevated tracking error of Portfolio 1, as well as its poor performance, may be due to the large allocation to financials. Figure 10 shows the sector allocations of the index as of the start of our study (December 31, 2007), along with the sector representations (by count of individual stocks) for the universe of the largest 50 constituents and our five 10-stock portfolios.[3] As suspected, the 30% allocation to financials in Portfolio 1 was the largest, whereas the best-performing Portfolio 4 had just a 10% allocation to this sector.

Implications of Changes in Market Conditions on Portfolio TEV

Using our time series of average single-stock volatility and average correlation estimated from 50 large-cap issuers, as shown in Figure 5, we obtain two estimates of these parameters:

- **Long-term** (January 2007-July 2014): single stock volatility 1.84%/day, correlation 44%
- **Recent** (YTD 2014): single stock volatility 1.05%/day, correlation 33%

Using the formulas developed above, we recalculate the theoretical relationship between the number of stocks in the portfolio and the TEV based on these two sets of parameter values obtained from the empirical data. The results shown in Figure 11 suggest that using the long-term averages, a 50-stock portfolio would have a TEV of about 18 bp/day. Achieving the same TEV in the current lower-volatility environment (using the YTD 2014 results) would require a more concentrated portfolio of about 20 stocks.

To check whether the change in estimated TEV is due to the change in volatilities or correlations, we also plot the estimate that would be obtained using the long-term estimate of single-stock volatility with the 2014 YTD estimate of correlation. We find that this results in TEV estimates that are only slightly higher than the long-term results; this is consistent with our above conclusion that a decrease in correlation should cause TEV to increase.

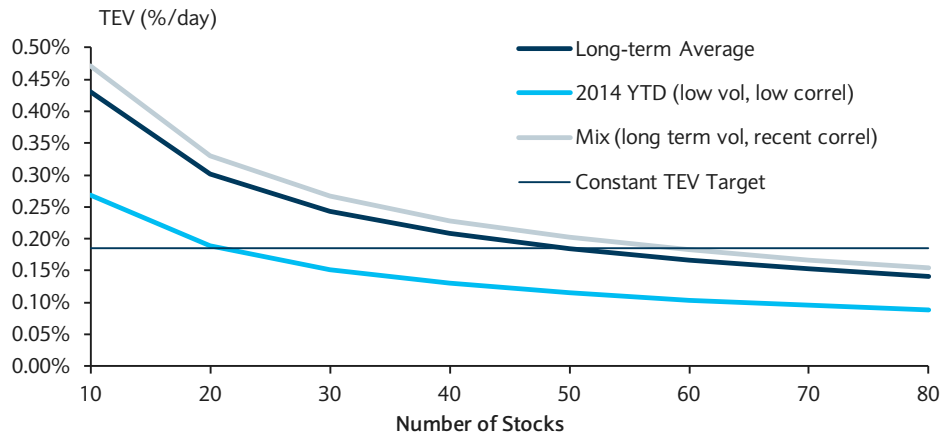
We therefore conclude that the primary effect that has driven TEV lower is a secular decrease in equity volatility. If these conditions persist, a portfolio manager who wishes to

[3] In fact, the allocations reported do not represent the full index, but only the 343 individual stocks that were in the index at both the start and end of the study period.

maintain the portfolio's issuer-selection TEV at a level similar to its value during higher-volatility periods would need to increase issuer concentrations. Of course, this would make the portfolio more vulnerable to an increase in TEV should volatilities revert to higher levels.

FIGURE 11

TEV as a function of number of stocks in portfolio, for volatility/correlation settings obtained empirically by averaging over two different time periods



Source: Barclays Research

Conclusion

We present a simple but robust approach to estimating the volatility and active risk of equity portfolios using just two parameters: the average single-stock volatility and the average pair-wise correlation. This model allows a manager to back into the level of issuer concentration needed to align active risk with a targeted risk budget, given the market volatility and correlations. Sensitivity analysis shows that changes in volatility have a stronger effect on active risk than changes in correlation.

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Richard Grinold and Ronald Kahn, *Active Portfolio Management: A Quantitative Approach for Producing Superior Returns and Controlling Risk*, 2nd Edition, 2000, McGraw-Hill.

Dynkin L., J. Hyman, and V. Konstantinovsky, *Sufficient Diversification in Credit Portfolios*, Barclays, December 14, 2010.

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