A Stochastic Analysis of Buy and Hold Versus Annual Rebalancing Portfolio Strategies

Michael Mattei*

Abstract

Numerous articles in the literature develop theoretical mathematical models that prove rebalancing investment portfolios will outperform a buy and hold strategy on a risk adjusted basis. However, a number of authors using varying asset classes and time periods have found instances where buy and hold outperforms a rebalancing strategy on a risk adjusted basis. This research shows that both can be correct. Most of the papers found in the literature use historical prices and price changes to validate their findings. The research effort detailed in this paper simulates a wide range of possible future asset pricing scenarios that do not rely on historical price patterns. These findings suggest that differences between these two strategies, at a more detailed level, favor the rebalancing strategy, but not exclusively.

Keywords: Investment Strategies, Investment Portfolio Performance, Portfolio Management

JEL Classification: C6, G1

I. Introduction

Which is better, buy and hold (BH) or annual rebalancing (RB), is a question that seems to linger in the investment management literature. Generally, but not always the research looks back 5, 10 or more years and uses monthly or annual returns to determine which approach results in higher risk adjusted portfolio returns. Using historical returns are essentially a sample that may not be representative of future return trends and patterns. In addition, authors select different types of assets classes for analysis making it difficult to compare the results of one research endeavor with others.

This paper presents empirical evidence, derived from extensive simulations conducted over diverse future market scenarios, which reveals RB is superior most of the time, but not always. By analyzing the performance of both buy and hold and annual rebalancing strategies under numerous "futures," the aim is to provide insights that have not been reported in the literature, specifically the details of the risk and returns for each trial, not just the overall results which is typical in the literature. Even Dichtl, H., Drobetz, W., & Wambach, M. (2016) who performed extensive analysis with 1000 simulations including buy & hold and nine different rebalancing strategies using a history-based bootstrap method only reported summary statistics, not specific details.

A large percentage of the literature examining which strategy produces the better returns indicates that annual or some form of periodic portfolio rebalancing leads to lower risk and higher returns. A sample of the papers include Dichtl, Drobetz & Wambach (2014), Maeso & Martellini (2020), Bouchey, Nemtchinov, Paulsen & Stein (2012), Meyer-Bullerdiek (2018) and Farago & Hjalmarsson (2023).

Dichtl, Drobetz & Wambach (2014) conclude that, "Despite cross-country differences, our history-based simulation results show that all rebalancing strategies outperform a buy-and-hold strategy in terms of Sharpe ratios, Sortino ratios, and Omega measures. The differences in risk-adjusted performance are not only statistically significant, but also economically relevant."

Buy and hold has many advocates although there does not appear to be quite as many publications in the literature. A sample of these papers include Hilliard & Hilliard (2018), Spinu (2015), Constable (2021) and Hulbert (2023). Masters (2003) highlights the often repeated conundrum, "While the power of rebalancing to improve returns and reduce risk is generally acknowledged … Who wants to take money from an asset class that has performed extremely well and reinvest it in something that has lagged behind?" The goal of this research is to provide insights at a greater level of detail than those reported in the literature by providing the probabilities of which strategy can provide superior returns, whether risk or non-risk adjusted.

II. Stochastic Process Methodology

A stochastic process is a "family or ensemble of time functions x(t, ζ) depending on the parameter ζ where the domain of ζ is the set of all experimental outcomes and the domain of t is a set of real numbers (Papoulis, 1991)." The Stochastic Comparison Model (SCM) developed for this research creates three arrays, one for each trial (Trial array), one for the randomly computed precent changes (Pct array) and a summary array for every trial (Outcome array).

The total portfolio value for both the BH and RB analyses is $100,000. The array for each trial is created using the following equations for the eight-asset class model. For the eight-asset class model, the beginning portfolio value for each asset class is set to $12,500 (12.5% of the total portfolio value). The two asset class model formulas are adjusted accordingly. For the 60% / 40% portfolio, the starting equity allocation is $60,000 and the initial bond allocation is $40,000. The value for t=0 is the initial portfolio value for each asset class at the beginning of month 1.

$$\mathrm{bh}(t, n) = \mathrm{bh}(t-1, n) * (1 + \mathrm{pct}(t, n)) \tag{1}$$

$$\mathrm{rb}(t, n) = \mathrm{rb}(t-1, n) * (1 + \mathrm{pct}(t, n)) \tag{2}$$

where t = 1 to 120 (10 years of monthly data), n is the number of asset classes and pct as defined in equation 4.

In the case of the RB portfolio, the year beginning portfolio value for each asset class needs to be reset back to the initial asset class proportions (traditional rebalancing) using the following equation:

$$\mathrm{rb}(\mathrm{t}) = \frac{1}{n}\sum_{i=1}^{n}(\mathrm{rb}(\mathrm{t}, \mathrm{i})) \tag{3}$$

where n=8 and when t is 12, 24, 36, … 108 (a multiple of 12) but not reset for t=120.

The values for pct in equations 1 and 2 are created using the Box Muller transform. For each trial, a corresponding array of random asset class percent changes (Pct array) is created with eight columns corresponding to the eight asset classes and 120 rows corresponding to the months for 10 years.

$$\mathrm{pct}(\mathrm{t}, \mathrm{n}) = \mu_n + \sigma_n\sqrt{-2\ln(\mathrm{U})} * \cos(2\pi\mathrm{V}) \tag{4}$$

where U is a single random number uniformly distributed in the interval (0,1) and where V is a single random number uniformly distributed in the interval (0,1) and μ_n = mean for n and σ_n = standard deviation for n. The values for the mean and standard deviation are taken from the first eight rows listed in the table in Appendix A. The means are the values in the column labeled Expected Return and the standard deviations are the values in the column by the same name.

Computing the Sharpe ratios requires calculating the mean and standard deviation for the percent change in the total portfolio value for each month (t). The results of equations 6 and 8 are appended to each row of the Trial array.

$$\text{bhtot(t)} = \sum_{i=1}^{n} (\text{bh(t, i)}) \tag{5}$$

$$\text{bhchg(t)} = (\text{ bhtot(t) / bhtot(t-1) }) \text{ -1} \tag{6}$$

$$\text{rbtot(t)} = \sum_{i=1}^{n} (\text{rb(t, i)}) \tag{7}$$

$$\text{rbchg(t)} = (\text{ rbtot(t) / rbtot(t-1) }) \text{ -1} \tag{8}$$

At the completion of each trial loop, a summary of the Trail array is computed and appended to the Outcome array. A row of the Outcome array includes the final portfolio values for each asset class and both strategies (equations 9 and 10). The final values from equations 5 and 7 (t=120) are also included in the row.

$$\text{bh}(\zeta,\text{n}) = \text{bh(t,n), where t=120 and n = the 8 ending portfolio values} \tag{9}$$

$$\text{rb}(\zeta,\text{n}) = \text{bh(t,n), where t=120 and n = the 8 ending portfolio values} \tag{10}$$

The following equations calculate the variables required for the Sharpe calculations and are appended to each trial row of the Outcome array.

$$\text{bhmean}(\zeta) = \frac{1}{t} \sum_{i=1}^{t} (\text{bhchg(i)}) \tag{11}$$

$$\text{rbmean}(\zeta) = \frac{1}{t} \sum_{i=1}^{t} \left(\text{rbchg(i)}\right) \tag{12}$$

$$\text{bhstd}(\zeta) = \frac{1}{t} \sum_{i=1}^{t} \sqrt{(\text{bhchg(i)} - \text{bhmean(i)})^2} \tag{13}$$

$$\text{rbstd}(\zeta) = \frac{1}{t} \sum_{i=1}^{t} \sqrt{(\text{rbchg(i)} - \text{rbmean(i)})^2} \tag{14}$$

The Outcome array with all 5000 trials is output for post processing. Since the Sharpe ratios from the SCM are monthly, they are annualized using the following formulas:

$$SR_{BH}(\zeta) = 12 * (\text{bhmean}(\zeta) - \text{riskfree}(\zeta))/(\sqrt{12} * \text{bhstd}(\zeta)) \quad (15)$$

$$SR_{RB}(\zeta) = 12 * (\text{rbmean}(\zeta) - \text{riskfree}(\zeta))/(\sqrt{12} * \text{rbstd}(\zeta)) \quad (16)$$

III. Validating the SCM

Dichtl, H., Drobetz, W., & Wambach, M. (2016) performed extensive analysis of numerous portfolio strategies including BH and nine different RB strategies. They ran 1000 simulations of each strategy using a history-based bootstrap method of Politis and Romano (1994). This bootstrap method randomly selects short segments of actual historical results and is intended to preserve time series properties not present in typical stochastic models. The descriptive statistics of their two asset classes are shown in Table 1 which are the ones applied to the SCM for validation.

Table 1: Asset Class Financial Statistics Used by Dichtl, et al.

	Mean	Standard Deviation
Stocks	10.45%	15.77%
Government Bonds	8.57%	7.91%
Cash	4.46%	0.77%

The first two rows of Table 2 compare the Sharpe ratios from Dichtl's BH and 60% - 40% RB portfolio to the those obtained from the SCM. It indicates that the results are very similar even though one is based on historical patterns and the other on simulated patterns. The third row compares the cross correlation between stocks and bonds for both research efforts.

Table 2: Comparison of SCM to Dichtl, et al. Results for 60% / 40% Portfolio

60% - 40% Portfolio	Dichtl, et al.	Stochastic Model
Buy & Hold	.552	.510
Annual Rebalancing	.579	.529
Stock/Bonds Correlation	.039	.0007

A test for robustness using a 20% stock and 80% bond portfolio is shown in Table 3. Two numbers are shown for the SCM to test the repeatability using a different set of random numbers. Once again the results are quite similar.

Table 3: Comparison of SCM to Dichtl, et al. Results for 20% / 80% Portfolio

20% Stocks - 80% Bonds	Dichtl, et al.	Stochastic Model
Buy & Hold	.668	.634/.637
Annual Rebalancing	.669	.638/.642
Stock/Bonds Correlation	.039	.0007/.0005

As reported by Dichtl, et al., many of the results for the 10% stock / 90% bonds and 20% stock / 80% bonds portfolios favored BH over RB strategies, however beyond a 20% equity allocation, RB consistently outperformed BH. It is interesting to note that while they did not give specific statistics for each of the 1000 simulations, Table 4 (joint probability table) provides detailed analysis of the 5000 trials from the SCM and demonstrates why researchers differ on which strategy outperforms. For example, in 2851 of the trials the RB ending portfolio value is greater than the BH portfolio AND the RB Sharpe ratio for the RB portfolio is better than the Sharpe ratio for BH. BH outperforms RB on both dimension for 843 trials of 5000 simulations. There are 926 trials where the BH ending value exceeds the RB portfolio but the RB Sharpe ratio is better and 380 trials where the RB ending portfolio value is greater than BH, but the BH portfolio has a better Sharpe ratio.

Table 4: Specific Details of the 60%/40% Portfolio Ending Values and Sharpe Ratios

60% Stocks - 40% Bonds		Sharpe Ratio (Frequency / % of Total)		
		RB>BH	BH>RB	Total
Ending	RB>BH	2851 / 57.0%	380 / 7.6%	3231/ 64.6%
Portfolio	BH>RB	926 / 18.5%	843 / 16.9%	1769 / 35.4%
Value	Total	3777 / 75.5%	1223 / 24.5%	5000 / 100.0%

Dichtl et al. (2016) state, "Our results show statistical evidence that rebalancing significantly outperforms buy-and-hold if the portfolio weight of stocks exceeds a certain threshold." The threshold is 20% stocks / 80% bonds. So the 60% stocks / 40% bonds portfolio significantly exceeds the threshold. However, drilling down into the details with SCM paints a more nuanced perspective on performance. Essentially RB outperforms BH 57.0% of the time on a risk adjusted basis, but BH outperforms 16.9% of the time on a risk adjusted basis. In the next section, the SCM is applied to an all-equity portfolio with eight diverse asset classes.

IV. Comparative Results for an All-Equity Portfolio

Application of the SCM to an all-equity asset class portfolio begins with two portfolios (BH and RB) each with a beginning balance of $100,000 equally distributed among eight equity asset classes with $12,500 initially invested in each asset class. The asset classes, their historical returns and standard deviations are the first eight rows of the table listed in Appendix A, specifically: US large cap growth, US large cap value, US mid-cap growth, US mid-cap value, US small cap growth, US small cap value, non-US developed market stocks and non-US emerging market stocks.

These asset classes were chosen for two reasons. First, they encompass a wide range of investment alternatives of non-overlapping equities. Second, allocating equal dollar amounts in each asset class helps to ensure a high degree of portfolio diversification that would not be obtained using common indexes such as the S&P 500 or the Russell 3000, both of which are market capitalization weighted.

The current iteration of the SCM does not model serial or cross correlation. Examining the random values over short periods, there are numerous times when the values exhibit some serial correlation by chance even though this was not specifically modeled. Cross correlation should have minimal impact on results since the identical random variables are applied to both portfolios at the same point in time.

This research assumes no transaction costs or the tax implication of rebalancing. The transaction cost assumption is now moot since most of the larger brokerage firms no longer charge commissions on stock and bond transactions. If the portfolios being analyzed are in a taxed deferred account then taxes have no impact on the performance of RB relative to BH. For taxable accounts however, the performance of the RB portfolio is impacted by the annual net profits or losses. Mattei (2018), required eight assumptions to calculate a reasonable estimate of the impact of taxes on the RB portfolio. He found that over the twenty-year period from 1997-2016, the annual return on the RB portfolio was 7.57% before taxes and 7.31% after taxes.

The modelling process follows equations 1 through 14 beginning with setting a loop counter to run 5000 separate trials. Table 5 depicts the basic summary statistics comparing the performance of the BH and RB strategies for the simulated futures. The average portfolio value at the end of 10 years for the BH approach is $303,718 and $298,703 for RB. The range for BH is $107,554 to $1,182,630 while for RB the range is $109,422 to $728,328.

The average compound annual growth rate for BH is 11.3% and 11.2% for RB. The CAGR is calculated by dividing the ending portfolio value for each trial and each strategy by $100,000 (the starting value of the portfolio), then taking the 10th root and subtracting 1. The averages shown in Table 5 are the arithmetic averages of the 5000 CAGRs for each strategy. These results indicate that BH generally performs somewhat better than RB on a non-risk adjusted basis, but not by a large amount except in a few cases of BH outliers.

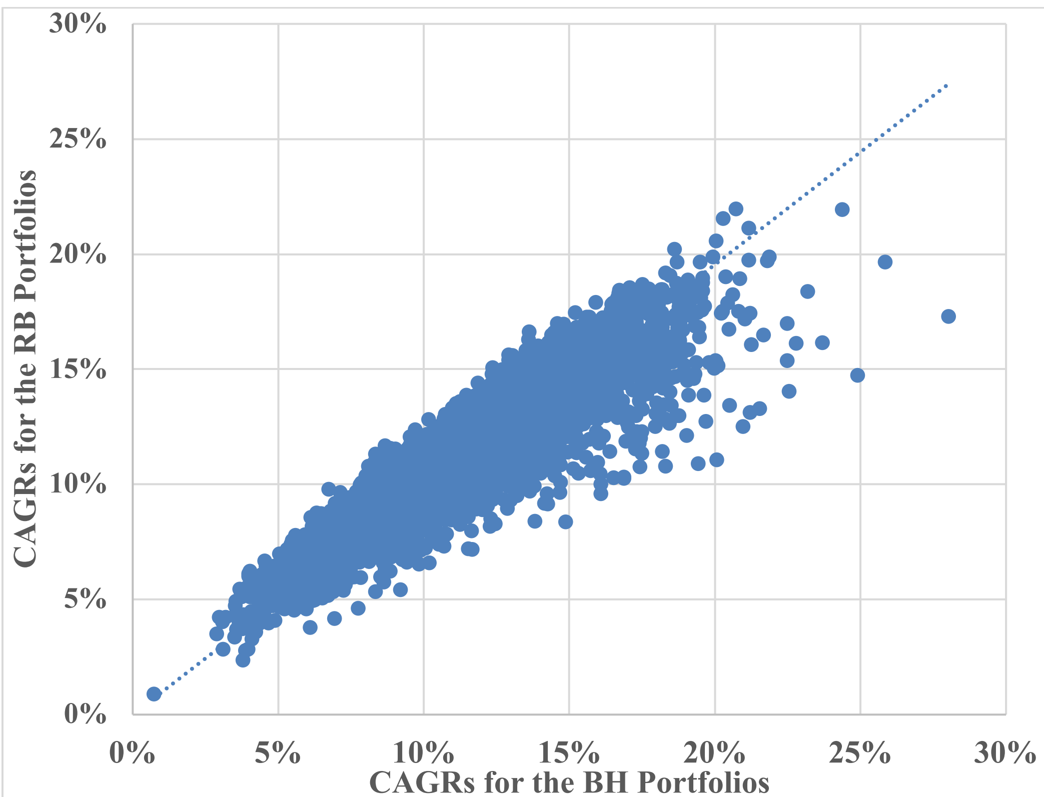
Table 5: Summary Statistics of Ending Portfolio Values, CAGR and Sharpe Ratios for the Two Strategies

Statistic	Buy & Hold	Annual Rebalance
Average Ending Portfolio Value	$303,718	$298,703
Min Ending Portfolio Value	$107,554	$109,422
Max Ending Portfolio Value	$1,182,630	$728,328
Average CAGR	11.3%	11.2%
Min CAGR	0.7%	0.9%
Max CAGR	28.0%	22.0%
Average Sharpe Ratio	1.108	1.221
Min Sharpe Ratio	0.010	0.029
Max Sharpe Ratio	2.323	2.452

Graphing the individual data points with the CAGR for the BH portfolios on the x-axis and the CAGR for the RB portfolios on the y-axis (similar to a QQ plot) provides a better insight into the performance of each strategy for each of the 5000 trials. Figure 1 is formatted so that the maximum value on the x-axis equals the maximum value on the y-axis to highlight how the values cluster around a trendline at approximately a 45° angle. If a point lands exactly on the trendline then the ending values for that trial are the same. Points above the trendline depict instances where the RB CAGR for a given trial exceeds the BH CAGR. Points below the trendline depict instances where the BH CAGR for a given trial exceeds the RB CAGR.

A linear regression of the data produces the equation: RB CAGR = .977 x BH CAGR with an R^2 = .985. The equation indicates that for every 1% increase in the BH CAGR, one can expect an approximately 0.977% increase in the corresponding RB CAGR. Therefore, the BH strategy will provide a slightly higher 10-year CAGR than the RB strategy on a non-risk adjusted basis. The chart also shows how rebalancing reduces variability of returns. The points above the regression line are tightly clustered on or above the regression line while there is a much higher degree of variability below and to the right of the regression line where the BH performance is better than the RB performance.

Figure 1: Scatter Chart of the CAGR for BH versus RB Portfolios



The most extreme outlier provides some noteworthy insights (the isolated point on the far right of the graph). The CAGR for BH is 28.02% and it is 17.31% for RB. The ending portfolio values are $1,182,602 and $493,548 respectively. The Sharpe ratios are quite close, 1.635 for BH and 1.685 for RB. While the BH portfolio has an ending value of more than twice the RB portfolio and the Sharpe ratios are quite close, the final asset class percentages are strikingly different (Table

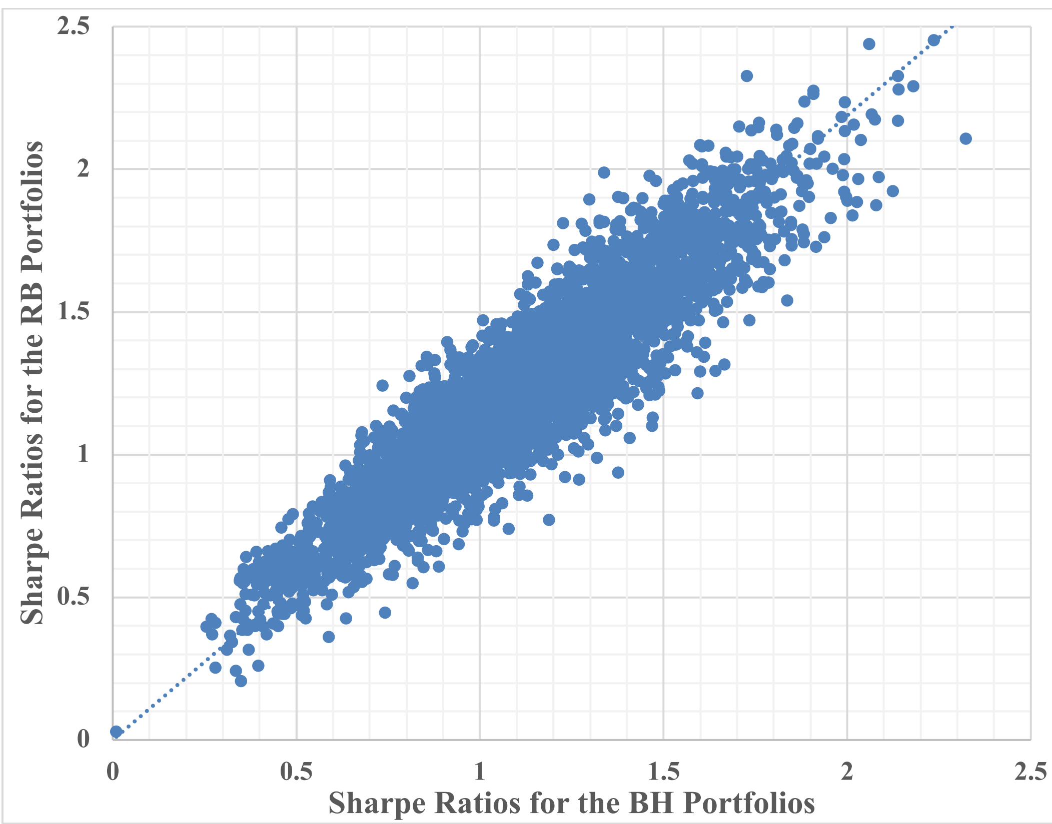
6). It should be noted that the RB portfolio is not rebalanced at the end of the final 12-month period so the values will not be exactly 12.5%. While there is a chance this outcome could occur in "real life," the simulation predicts that is will occur only once in 5000 futures or a .02% probability.

Table 6: Ending Asset Class Percent of the Total Portfolio Ending Value for the Extreme Outlier Example

	Asset Class 1	Asset Class 2	Asset Class 3	Asset Class 4	Asset Class 5	Asset Class 6	Asset Class 7	Asset Class 8
BH	1.0%	1.6%	2.5%	1.6%	1.6%	8.5%	8.9%	74.4%
RB	10.0%	10.1%	12.5%	14.4%	13.6%	11.1%	10.4%	17.8%

The Sharpe ratio chart (Figure 2) is also formatted so that the maximum value on the x-axis equals the maximum value on the y-axis to highlight how the values cluster around a trendline at approximately a 45° angle. If a point lands exactly on the trendline then the Sharpe ratios for that trial are the same. Points above the trendline depict instances where the RB Sharpe ratios for a given trial exceeds the BH Ratio. Points below the trendline depict instances where the BH Sharpe ratio for a given trial exceeds the RB Ratio.

Figure 2: Scatter Chart of the Sharpe Ratios for BH versus RB



A linear regression of the data points in Figure 2 produces the equation where the RB Sharpe ratio = 1.094 x BH Sharpe ratio with an R^2 = .9886. The equation indicates that for every 0.1 increase in the BH Sharpe ratio, one can expect an approximately .1094 increase in the corresponding RB Sharpe ratio. Therefore, while the BH strategy provides slightly higher CAGRs and ending portfolio values, the RB strategy provides slightly higher risk adjusted rates of return.

V. Conclusions

Most authors agree that rebalancing a portfolio reduces risk, but it can result in reduced performance by selling high performing assets too soon. This has led some researchers such as Dai, TS., Chen, BJ., Sun, YJ. et al. (2024), Sandy Rattray, Nick Granger et al. (2020) and others to propose alternate rebalancing strategies to take advantage of "holding winners" longer. Essentially trying to capture some of the benefits of BH while also reducing the risk inherent in a BH strategy.

Table 7 of joint probability distributions (value on the right) provides a detailed breakdown of the performance differences between the two portfolio strategies by ending portfolio value and Sharpe ratios. The ending portfolio value for the RB portfolios is higher than BH 55.3% of the time. In all but 35 trials, the Sharpe ratio is higher for the RB portfolio. While the ending value for the BH portfolios are higher 44.7% of the time the Sharpe rations for the BH strategy is better than RB strategy only 17.6% of the time. These results seem to support the potential for alternate RB strategies that can capture some of the BH performance without the higher risks associated with asset concentration.

Table 7: Specific Details of the Ending Portfolio Values and Corresponding Sharpe Ratios

8 Equity Asset Classes		Sharpe Ratio Frequency / % of Total		
		RB>BH	BH>RB	Total
Ending	RB>BH	2730 / 54.6%	35 / 0.7%	2765 / 55.3%
Portfolio	BH>RB	1357 / 27.1%	878 / 17.6%	2235 / 44.7%
Value	Total	4087 / 81.7%	913 / 18.3%	5000 / 100.0%

A closer look at the risks induced by asset class concentrations are shown in Table 8. For the BH portfolios, the asset class weights after 10 years are shown in the third column and the ending percentages for the "traditionally" rebalanced portfolio are in the fourth column. There is a very high correlation (.994) between the expected return of the asset class and its weight at the end of 10 years for the BH portfolio.

Table 8: Ending Asset Class Weights for BH and RB Compared to Expected Returns

Asset Class	Expected Return	Average Ending Asset Class Weight in the Portfolio for the BH Strategy	Average Ending Asset Class Weight in the Portfolio for the RB Strategy
U.S. Large-cap Growth Stocks	8.25%	9.5%	12.1%
U.S. Large-cap Value Stocks	9.60%	11.1%	12.4%

U.S. Mid-cap Growth Stocks	10.41%	11.8%	12.4%
U.S. Mid-cap Value Stocks	12.48%	14.2%	12.7%
U.S. Small-cap Growth Stocks	9.98%	10.9%	12.3%
U.S. Small-cap Value Stocks	13.29%	15.3%	12.7%
Non-U.S. Dev Stocks	10.02%	11.5%	12.4%
Non-U.S. Emerging Stocks	14.35%	15.8%	12.9%

The results of this research demonstrate that one cannot know which strategy will outperform the other even as the market is unfolding, but the traditional RB strategy outperforms BH 81.7% of the time on a risk adjusted basis. Over an 80% probability of outperformance strongly supports the RB strategy. However the results of this research also indicate that BH outperforms RB on a risk adjusted and ending portfolio value basis 17.6% of the time. This result strongly supports the use of non-traditional rebalancing strategies that can capture some of the benefits of a BH strategy without the inherent weaknesses.

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Appendix A: Historical Returns for Common Asset Classes from Morningstar (2024)

Asset Class	Return Data Series (Benchmark)	Expected Return	Standard Deviation
U.S. Large-cap Growth Stocks	Russell Top 200 Growth	8.25%	21.82%
U.S. Large-cap Value Stocks	Russell Top 200 Value	9.60%	17.47%
U.S. Mid-cap Growth Stocks	Russell Midcap Growth	10.41%	23.22%
U.S. Mid-cap Value Stocks	Russell Midcap Value	12.48%	19.17%
U.S. Small-cap Growth Stocks	Russell 2000 Growth	9.98%	27.62%
U.S. Small-cap Value Stocks	Russell 2000 Value	13.29%	22.46%
Non-U.S. Dev Stocks	MSCI EAFE	10.02%	20.62%
Non-U.S. Emerging Stocks	MMSCI Emerging Mkts	14.35%	29.65%
U.S. Investment Grade Bonds	Barclays US Agg Bond TR USD	3.36%	7.08%
U.S. High-Yield Bonds	Barclay US Corp High Yield	7.37%	11.33%
Non-U.S. Dev Bonds	Citi WGBI Non-USD USD	3.08%	11.22%
Cash	Citi Treasury Bill 3 Mon USD	0.97%	1.67%
Commodities	DJ UBS Commodity TR	4.48%	17.86%
U.S. Real Estate	FTSE NAREIT-Equity	8.92%	23.55%