Portfolio Rebalancing
Part 1 of 2: Strategic Asset Allocation

Antti Ilmanen
Portfolio Solutions Group

Thomas Maloney
Portfolio Solutions Group

December 2015

Decisions relating to portfolio rebalancing can be considered an active investment strategy and have important implications for portfolio returns.

In this article, we explore the key considerations for investors deciding whether and how to rebalance liquid strategic asset portfolios. Our results suggest that the ability to capture price trends has tended to be at least as important as cost efficiency in driving the relative long-term performance of different rebalancing processes.

A companion article (Part 2) examines common misconceptions about the role and implications of rebalancing, particularly in the context of actively managed portfolios.

We thank Gregor Andrade, Cliff Asness, Jeff Dunn, John Huss, Ronen Israel, Lars Nielsen, Christopher Palazzolo, Scott Richardson and Rodney Sullivan for helpful comments and suggestions.

AQR Capital Management, LLC
Two Greenwich Plaza
Greenwich, CT 06830

p: +1.203.742.3600
f: +1.203.742.3100
w: aqr.com

Introduction

In this article, we explore the most important considerations for investors deciding whether and how to rebalance to strategic weights (say, a 60/40 stock/bond allocation), combining brief theoretical discussion with an illustrative empirical analysis.

Our results suggest that many sensible rebalancing strategies may confer similar long-term risk benefits. In order to choose between these variants, investors need to take a view not only on likely implementation costs, but, more importantly, on future asset price behavior — specifically, the extent to which prices may exhibit trends or mean reversion. Trending prices tend to favor less frequent rebalancing.

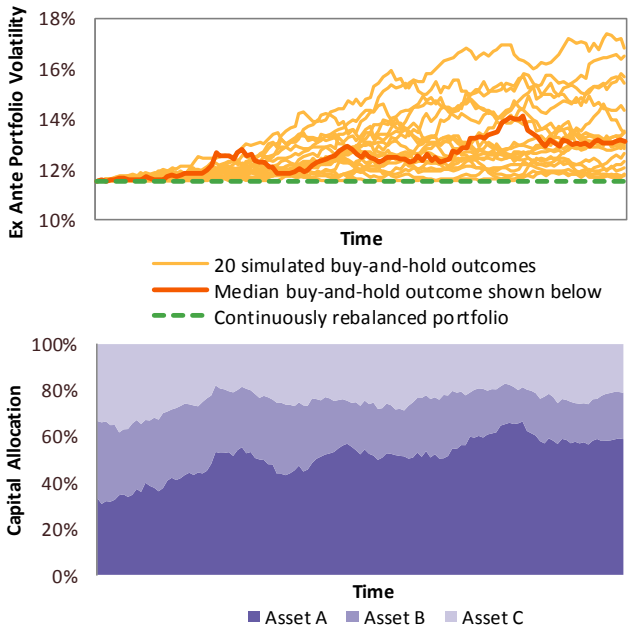
Most investors' strategic portfolios are based on target capital (or dollar) allocations, and we follow this long-established approach in the present article. In our companion article we discuss the benefits of rebalancing to target *risk* allocations and risk levels (i.e., accounting for differing riskiness across investments and through time). This is typically a more dynamic process.

Deciding Whether to Rebalance

Few investors even consider the possibility of not rebalancing at all[1] — and with good reason, as we will demonstrate — but examining *why* we rebalance helps us to ask the right questions when choosing *how* to rebalance. Rebalancing has risk, return and cost implications, and all three should be considered. The risk and cost implications are foreseeable. The return implications are harder to predict, but some rules of thumb can be helpful.

Risk Implications: A buy-and-hold portfolio (i.e., no rebalancing) that is initially well-diversified tends to become less diversified over time, as winners earn themselves higher weights and losers shrink to smaller weights. Its risk level is therefore likely to be less stable, and to rise over time. **Exhibit 1** shows ex ante volatility (one measure of riskiness) for 20 simulations of a buy-and-hold portfolio of 3 theoretical assets with equal starting allocations, equal expected returns and constant volatilities. The portfolio risk level fluctuates as allocations rise and fall.[2] We show the allocations for a typical outcome, where one asset comes to dominate over time. *Rebalanced portfolios are likely to retain their portfolio-level risk characteristics better than buy-and-hold portfolios.*

Exhibit 1: Ex-Ante Volatility and Allocations for Simulated Buy-and-Hold Outcomes



Source AQR. For illustrative purposes only, not indicative of an actual portfolio or actual investments. Simulated monthly returns over 10 years for 3 uncorrelated assets with constant expected volatility of 20%, expected Sharpe ratio of 0.5 and normally-distributed serially-independent returns. Portfolios start with equal allocations to the 3 assets.

[1] Sharpe (2010) argues that a buy-and-hold (or adaptive) portfolio has the advantage of better macro consistency, but it is not clear that this advantage is aligned with investor objectives, given the possibility of significant drift over time in asset class weights and portfolio risk.

[2] For a buy-and-hold portfolio of equities and bonds, the risk level is likely to experience cyclical variations, with equities having a higher weight after equity bull markets, and a lower weight after bear markets. Over a longer period, the asset class with the higher expected return (i.e., equities) will likely come to dominate the portfolio.

Return Implications: For many investors, the risk implications are sufficient reason to rebalance, and only the cost-minimizing implementation details (frequency, tolerance bands, etc.) remain to be decided. But rebalancing to constant weights is also an *active contrarian strategy* when compared to a buy-and-hold benchmark.[3] Rebalancing to constant weights involves selling winners and buying losers, and tends to be profitable during periods when investments have either similar or mean-reverting performance, and costly when investments have either persistently divergent or trending outcomes. It is difficult to predict which return pattern will prevail for a given set of investments over a given horizon. Rebalancing is "short a regime change" — that is, it can suffer when the world changes or when initial assumptions turn out to be false.

A buy-and-hold approach may be preferable for a portfolio of investments with highly uncertain expected returns, likely to have widely dispersed outcomes over the investment horizon (or even fall to near-zero value — examples could be small-cap equity or venture capital portfolios). A rebalanced approach may be preferable where the portfolio components are "tried and true" long-term investments, such as entire asset classes.[4]

A related but distinct consideration is whether the investments exhibit trending or mean-reverting behavior over shorter horizons. This — together with the expected transaction costs — may have implications for both the likely return impact and the preferred frequency of rebalancing, as we discuss later.

The impact of rebalancing on expected returns is rather subtle and much debated — it is discussed further in Part 2 of this series. Essentially, by preventing winners from earning higher weights, and losers from decaying to lower weights, rebalancing neutralizes *compounding effects* within the portfolio. In other words, a rebalanced portfolio forgoes the very best potential buy-and-hold outcomes, where winning investments keep on winning and persistent losers fizzle out to small, inconsequential weights. But as shown in Exhibit 1, it also tends to maintain a lower risk level by preventing the concentration of risk among winning investments.[5]

For these reasons, rebalancing tends to *reshape* the distribution of potential portfolio outcomes, making it narrower and less positively skewed. This increases the median outcome while leaving the mean unchanged, meaning that a rebalanced portfolio is more likely to realize positive returns — and more likely to realize returns exceeding the mean expectation — over the investment horizon.

Cost Implications: Rebalancing incurs costs. Our analysis suggests that transaction costs from rebalancing liquid assets may be modest, and for most investors costs shouldn't dictate whether or not to rebalance. They may, however, influence the decision of *how* to rebalance.

Deciding How to Rebalance

When designing a rebalancing process there are two[6] main decisions to be made:

- When to rebalance? (How often? Fixed schedule or trigger-based system?)

[3] We might equally say that choosing *not* to rebalance is an active *momentum*-biased strategy compared to a rebalanced benchmark. One might argue that a continuously rebalanced portfolio is a more justifiable strategic benchmark. However, in this article we follow the literature in viewing the buy-and-hold portfolio as the passive benchmark.
[4] This distinction is discussed in Ang (2014).
[5] Harvey et al (2014) suggest a rebalanced portfolio is susceptible to larger drawdowns than a buy-and-hold portfolio. This is true for two portfolios entering a period of sustained investment losses with the same weights, as the authors illustrate: the rebalanced portfolio keeps buying the losing investments. However, this analysis misses the tendency of rebalanced portfolios to be already better diversified at the onset of such periods. When considered in the context of longer investment horizons, rebalanced portfolios tend to experience *smaller* drawdowns because of their lower average risk level (see later analysis). Harvey et al.'s arguments regarding the complementarity of rebalancing and momentum are, however, persuasive, as we illustrate later.
[6] A third decision is whether to rebalance major asset classes only, or also regional allocations (see NBIM 2012).

- How much to rebalance? (Fully back to the benchmark, or only partially?)

Norges Bank Investment Management's (NBIM) discussion note on rebalancing (2012) provides a useful combination of theoretical discussion and empirical results. Some researchers[7] have designed explicitly optimized rebalancing processes, but the expected additional benefits of these may be small for a strategic portfolio with static or slow-moving allocation targets (by contrast, dynamic strategies with much higher turnover may expect significant benefits from cost-optimized rebalancing).

In our view, there are three main determinants of which method may be preferred for a given investor, relating to risk preferences, costs and return expectations.

Determinant 1: Tolerance of short-term variations in portfolio risk characteristics

Under plausible assumptions and for reasonable choices of frequency and/or tolerance bands, most rebalancing processes will maintain long-term risk characteristics almost equally well (this important observation is supported by the empirical analysis in the next section). However, some will permit a larger short-term tracking error away from the strategic benchmark risk characteristics (including allocations, ex ante volatility and equity beta).

Determinant 2: Expected costs

These may include:

- Transaction costs (bid-ask and market impact)
- Operational costs (internal or external management expenses or fees)
- Tax implications for taxable investors (e.g., if rebalances trigger capital gains tax liability)

Higher costs will favor less-frequent or partial rebalancing, or wider tolerance bands. Note that it may be cost-efficient to use dividend or coupon payments to rebalance where possible (by reinvesting in a different asset class), reducing the need to sell underlying securities. Fund contributions and distributions may also be integrated in the rebalancing process where possible.

Determinant 3: Expectations of trending or mean-reverting investment performance

If investment returns exhibit trends or mean reversion, the rebalancing frequency can affect expected portfolio returns. Rebalancing at or within the frequency of any mean-reversion patterns will tend to earn positive returns, while rebalancing at or within the frequency of any momentum effects will be fighting against these and therefore tend to suffer negative returns. There is evidence that many investments exhibit 3- to 12-month momentum,[8] which may be exploited by less-frequent rebalancing (annual or lower frequency). This can allow winning and losing trends to "play out" and compound between rebalances.

The Pitfalls of Discretionary Rebalancing

Some investors may consider rebalancing (or not rebalancing) an opportunity to express discretionary tactical market views — for example, based on the current or expected macroeconomic environment. We believe tactical market timing is more difficult than hindsighted narratives suggest,[9] even without the constraint of expressing views only in the context of a rebalancing decision. The momentum effects mentioned above may be one of the better market timing indicators, but these, too, are low-conviction signals when applied to a single market. Any tactical views should be applied with humility and caution, and a predefined, rule-

[7] See for example Sun et al (2006).

[8] See for example Hurst, Ooi and Pedersen (2012).
[9] See AQR *Alternative Thinking* 4Q2014.

based rebalancing strategy may be the best way to ensure that diversification is maintained.[10]

A Simple Empirical Analysis

We build a simple strategic portfolio similar to the liquid portion[11] of many institutional portfolios (see **Exhibit 2**), and examine several rebalancing approaches using 43 years of monthly return data since 1972. To increase the breadth of events in the sample period with potential rebalancing implications, we include two equity and two bond allocations, as well as a small commodity allocation. With an even simpler two-asset U.S. stock/bond portfolio, the main conclusions are similar, though results differ in details (see appendix).

Exhibit 2: Strategic Portfolio Allocations

Asset Class	Target Alloc.	Proxy Index
U.S. Equities	30%	MSCI US
Non-U.S. Equities	20%	MSCI World ex US
U.S. Govt. Bonds	20%	Barclays US Tsy Intermediate*
Non-U.S. Govt Bonds	20%	Barclays Glob Ex US Tsy Hedged*
Commodities	10%	GSCI

Source: AQR. From January 1972 to December 1972, U.S. Govt. Bond proxy is 10-year Treasury. From January 1972 to December 1986, Non-U.S. Govt. Bond proxy is a GDP-weighted portfolio of G6 ex U.S. 10-year bonds.

Exhibit 3 (upper panel) shows the impact of six different rebalancing schedules on amount of variation in allocations, performance and turnover, compared to buy and hold. For the annual and biennial processes we show statistics averaged across all the possible quarter-end rebalance schedules. The three trigger-based processes rebalance all investments when the allocation of any investment under- or overshoots by a given percentage of its target level (see appendix for details of threshold calculation).

The first two rows show ex ante measures of variation. As we would expect, the average allocation range depends on the frequency of rebalancing, with more frequent schedules or tighter trigger thresholds keeping allocations closer to their targets. However, compared to buy-and-hold, all the rebalanced portfolios have more stable ex ante volatility (second row).

Similarly, compared to buy-and-hold, all the rebalanced portfolios have higher returns, lower and more stable realized volatility, and smaller drawdowns. These performance characteristics improve roughly the same amount regardless of frequency of rebalancing.

A similar pattern is seen in the lower panel, which shows the impact of the *degree* of rebalancing — how far we rebalance toward the target allocations. The more complete rebalancing processes achieve tighter allocation ranges, but all the processes (even rebalancing only 25% toward targets) achieve similar improvements in long-term performance statistics in this analysis.

The last row in each panel shows that direct transaction costs are relatively modest (a few basis points), even for frequent or complete rebalancing (compared to, for example, those faced by active investment strategies). Turnover can be reduced by (1) less frequent rebalancing or (2) partial rebalancing, but both also allow more short-term variation in allocations. Of these two variables, partial rebalancing gives a larger cost saving for a smaller increase in allocation ranges.

The Role of Momentum and Reversal Effects

One noticeable result in Exhibit 3A is that during this period and for these investments and proxies, annual and biennial schedules outperformed

[10] Some authors (e.g., Gort and Burgener, 2014) have argued that rebalancing using option positions has the advantage of effectively taking the rebalancing mechanism (and any temptation to override it) out of the investor's hands before price moves trigger a rebalance. This method has typically been proposed to rebalance the equity allocation only, by selling a straddle with strike prices set according to the chosen tolerance band. This strategy combines rebalancing and volatility-selling and is beyond the scope of this short article.

[11] Illiquid investments are difficult and expensive to rebalance. This difficulty and cost should be taken into account when deciding on the sizing of any illiquid asset allocations.

Exhibit 3: Hypothetical Performance of Different Rebalancing Methods 1972-2014

A. Impact of Schedule

	Impact of Schedule	Buy and Hold	Calendar-based Rebalance			Trigger-based Rebalance		
			Biennial	Annual	Monthly	+/-30%	+/-20%	+/-10%
Ex Ante	Avg Allocation Range*	104%	95%	70%	27%	67%	52%	35%
	Vol of Ex Ante Volatility*	2.3%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Performance	Net Total Return	8.7%	9.3%	9.2%	9.0%	9.1%	9.1%	9.0%
	Volatility	9.0%	8.0%	8.0%	8.1%	8.3%	8.2%	8.1%
	Net Sharpe Ratio	0.32	0.44	0.43	0.39	0.40	0.40	0.40
	Vol of Realized Volatility*	2.5%	1.8%	1.8%	2.0%	2.0%	2.0%	2.0%
	Max Drawdown	-41.2%	-29.7%	-29.7%	-32.8%	-32.6%	-32.8%	-32.8%
Turnover	Annual Turnover	0.0%	5.1%	9.2%	26.0%	6.3%	9.4%	13.8%
	Avg # Rebals / Year	0.0	0.5	1.0	12.0	0.4	0.9	2.3
	Avg Trade Size	NA	10.3%	9.2%	2.2%	16.8%	11.0%	6.0%
	Annual Trade Cost*	0.00%	0.03%	0.05%	0.13%	0.03%	0.05%	0.07%

B. Impact of Degree

	Impact of Degree	Buy and Hold	Annual Rebalance			Monthly Rebalance		
			25%	50%	100%	25%	50%	100%
Ex Ante	Avg Allocation Range*	104%	101%	86%	70%	42%	34%	27%
	Vol of Ex Ante Volatility*	2.3%	1.8%	1.9%	2.0%	2.0%	2.0%	2.0%
Performance	Net Total Return	8.7%	9.2%	9.3%	9.2%	9.0%	9.0%	9.0%
	Volatility	9.0%	8.1%	8.0%	8.0%	8.0%	8.1%	8.1%
	Net Sharpe Ratio	0.32	0.41	0.43	0.43	0.40	0.40	0.39
	Vol of Realized Volatility*	2.5%	1.9%	1.9%	1.8%	1.9%	2.0%	2.0%
	Max Drawdown	-41.2%	-31.2%	-30.1%	-29.7%	-31.7%	-32.5%	-32.8%
Turnover	Annual Turnover	0.0%	3.1%	5.3%	9.2%	10.9%	15.8%	26.0%
	Avg # Rebals / Year	0.0	1.0	1.0	1.0	12.0	12.0	12.0
	Avg Trade Size	NA	3.1%	5.3%	9.2%	0.9%	1.3%	2.2%
	Annual Trade Cost*	0.00%	0.02%	0.03%	0.05%	0.05%	0.08%	0.13%

Source: AQR. "Avg alloc range" is [(Max-min allocation) / target allocation], averaged across asset classes. "Vol of ex ante vol" is volatility of ex ante volatility based on rolling 36-month covariance matrix. Gross total return is annualized arithmetic rate of return. Returns and Sharpe ratios are net of estimated transaction costs from rebalancing, gross of fees. Risk-free rate is 3-month T-Bill rate. "Vol of realized vol" is volatility of rolling 36-month volatility. Annual trade cost assumes uniform transaction cost of 0.5% for all asset classes. Allocations are as described in Exhibit 2. Hypothetical data has inherent limitations, some of which are disclosed herein.

monthly or trigger-based schedules. This is apparently due to better harnessing of multi-month momentum effects by less frequent, calendar-based processes. This outperformance by less frequent schedules passes various robustness checks. As well as the average outperformance shown in Exhibit 3, each of the March, June, September and December annual schedules outperforms monthly rebalancing, over the full sample and in both halves of it. These sub-results are shown in **Exhibit 4**.

Exhibit 4: Hypothetical Sharpe Ratios for Different Rebalancing Methods 1972-2014

Period	Buy & Hold	Annual Rebalance				1M Rebal
		Mar	Jun	Sep	Dec	
1972-2014	0.32	0.43	0.43	0.43	0.43	0.39
1972-1993	0.34	0.36	0.36	0.41	0.38	0.35
1993-2014	0.32	0.50	0.49	0.46	0.49	0.43

Source: AQR. Hypothetical Sharpe ratios net of transaction costs, based on monthly data. Risk-free rate is 3-month T-Bill rate. Allocations are as described in Exhibit 2.

To help understand this outperformance, we show in **Exhibit 5** autocorrelations observed in the asset returns used in our analysis. All asset

classes tended to display positive autocorrelation (momentum) at frequencies of up to one year, and negative autocorrelation (mean reversion) at 3- to 5-year frequencies.

Exhibit 5: Autocorrelations in Asset Excess Returns 1972-2014

Frequency	US EQ	INT EQ	US FI	INT FI	COM	Mean
1 month	0.04	0.11	0.15	0.26	0.17	0.15
3 months	0.09	0.12	0.00	0.15	0.05	0.08
12 months	0.05	0.11	0.21	0.12	-0.04	0.09
3 years	-0.25	-0.37	-0.18	-0.51	-0.33	-0.33
5 years	-0.13	-0.45	0.01	-0.65	-0.34	-0.31

Source: AQR. Asset class proxies are as described in Exhibit 2.

When we compare the returns earned by buy-and-hold and frequently rebalanced portfolios, these momentum and reversal effects at different horizons tend to offset each other. The frequently rebalanced portfolio suffers a drag from short-term momentum, but earns a bonus from longer-term mean-reversion. Annually or biennially rebalanced portfolios, however, get the best of both worlds in this sample: they behave like buy-and-hold portfolios at shorter horizons (harnessing momentum), but like rebalanced portfolios at longer horizons (harnessing reversals).[12]

Trigger-based processes appear not to enjoy the same advantage. For example, the +/-20% threshold triggers roughly one full rebalance per year on average, and achieves tighter allocation ranges than a fixed annual process, for similar turnover.[13] However, it underperforms the latter, probably because it tends to trigger rebalances during trend events (see appendix). A fixed annual schedule that is indifferent to within-year market moves is more likely to allow trends to play out.

[12] Rebalancing even less frequently — every three or five years — still captures this advantage. At 10 years, the benefit begins to fade as full mean-reversion cycles occur between rebalances.

[13] It also has the advantage of reducing the element of chance introduced by an arbitrary calendar-based schedule. The timing of rebalances can have a significant and discomfiting short-term impact during a major market event like the Global Financial Crisis of 2008.

Investors must decide whether the patterns shown in Exhibit 5 are persistent and reliable enough to influence the design of a rebalancing process. Certainly, evidence of 3- to 12-month momentum effects has been observed in many different asset classes and as far back as data permits us to go. Multi-year mean reversion patterns are also seen in many contexts, but perhaps less consistently. Over the course of a shorter investment horizon of 5 or 10 years, mean reversion may not occur.

Allocations Through Time

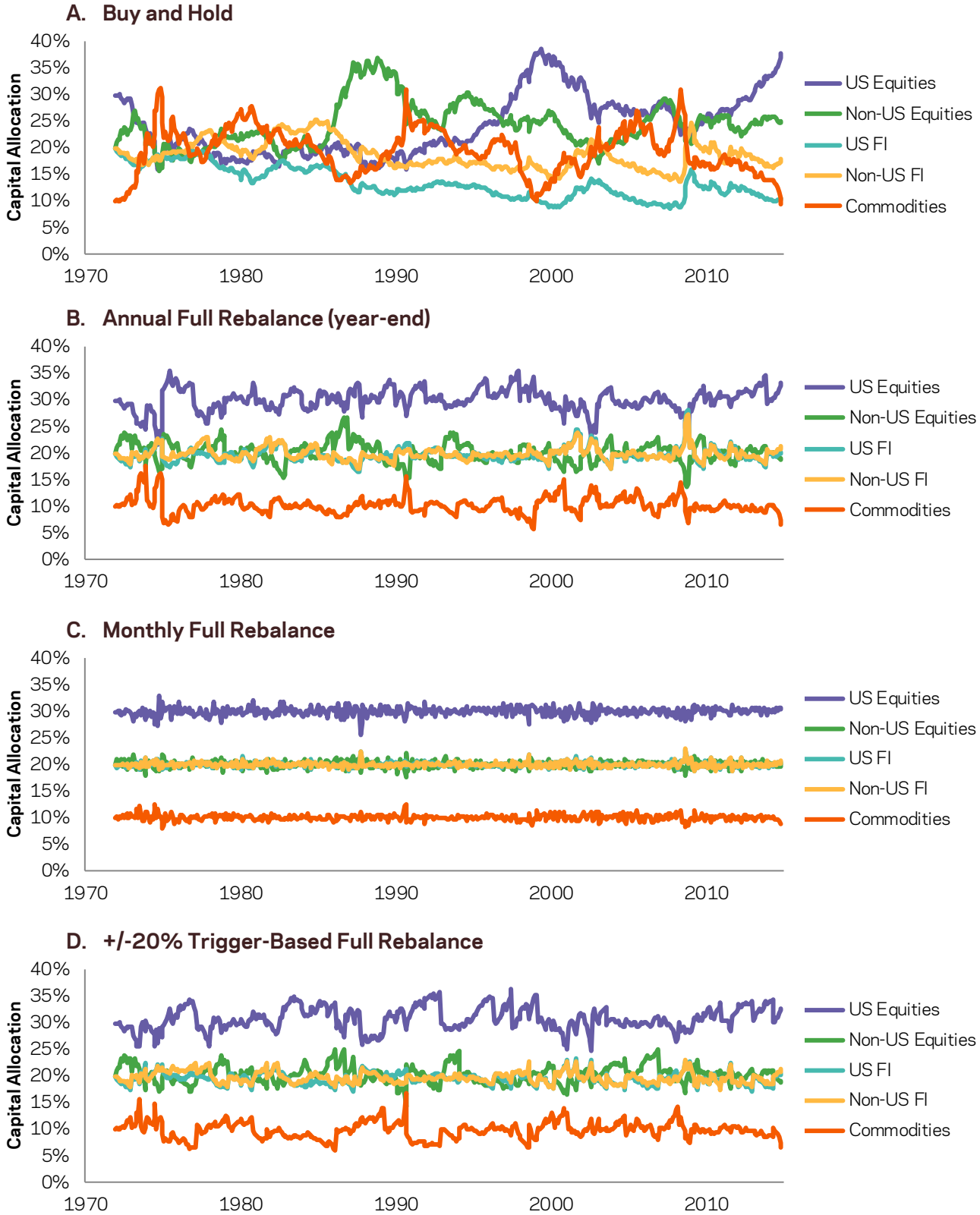
Exhibit 6 shows allocations over time for four of the strategies discussed in this analysis. The drifting buy-and-hold allocations are clearly evident. For example, outperformance by U.S. equities led to above-target allocations in 1999 and 2014. Also clearly visible is the varying degree of stability in allocations achieved by the different rebalancing processes. It may seem surprising that, as discussed above, all of these rebalancing processes achieve similar reductions in volatility and drawdowns.

Conclusions

Rebalancing is not a surefire winner: the return impact will always depend on investment outcomes. The risk impact may be more predictable: over the longer term, rebalancing tends to lead to more predictable risk characteristics, while seemingly passive buy-and-hold portfolios are likely to have more variable risk outcomes.

Our analysis suggests that many reasonable rebalancing processes may be expected to achieve the objective of maintaining portfolio diversification over the long-term (this can also be demonstrated more generally, using simulated

Exhibit 6: Hypothetical Proxy Portfolio Capital Allocations 1972-2014



Source: AQR. Please see Exhibit 2 for portfolio constituents. Hypothetical data has inherent limitations, some of which are disclosed herein.

data). When choosing implementation details, the most important trade-off appears to be between experiencing short-term variations in allocations and harvesting historically-observed price momentum effects. Investors should therefore balance their tolerance for such variations against their expectation or belief that multi-month price momentum effects will continue in the future.

Cost considerations may be secondary to the above effects, as our analysis suggests that expected transaction costs for rebalancing liquid investments to fixed targets are modest — but they are also more certain. Cost considerations tend to favor partial or less-frequent rebalancing. Partial rebalancing is the more efficient cost-reduction measure if price momentum effects are ignored (it gives a bigger turnover reduction for a smaller increase in allocation drift). In the presence of momentum, less-frequent rebalancing may be preferred.

One approach that we do not analyze here is an explicit momentum strategy, either overlaid on the rebalancing process — as proposed by Harvey et al. (2014) — or given its own allocation. This may be less palatable or less practicable for some institutions,[14] but it may also be a more efficient and less constrained way to benefit from time series momentum. Whether investors choose to integrate or keep separate their views on rebalancing and time-varying expected returns, we hope that a better understanding of the implications of rebalancing choices may help them to make an informed decision.

[14] For a discussion of institutional preferences for contrarian rather than momentum-based tactical views, see *AQR Alternative Thinking*, 4Q2014.

Appendices

Simple U.S. 60/40 Portfolio

Exhibit A1 repeats the empirical analysis for a simple 60/40 portfolio of U.S. stocks and bonds.[15] For this portfolio there is less difference between buy and hold and the various rebalanced approaches. However, the results are broadly consistent with those in the main article, namely that (1) all the rebalancing methods produce similar performance and risk improvements compared to buy and hold, and (2) infrequent calendar-based schedules appear to give the best long-term performance by better capturing momentum effects.

Further Analysis on Trigger-Based Rebalancing

Specifying trigger thresholds is as much art as science. We use a combination of relative, absolute and volatility-adjusted inputs, in an

Exhibit A1: Hypothetical Performance of Different Rebalancing Methods 1972-2014

A. Impact of Schedule

	Impact of Schedule	Buy and Hold	Calendar-based Rebalance			Trigger-based Rebalance		
			Biennial	Annual	Monthly	+/-30%	+/-20%	+/-10%
Ex Ante	Avg Allocation Range*	73%	58%	47%	21%	33%	25%	22%
	Vol of Ex Ante Volatility*	2.4%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
Performance	Net Total Return	8.7%	8.8%	8.8%	8.7%	8.8%	8.7%	8.7%
	Volatility	10.0%	9.3%	9.4%	9.5%	9.5%	9.5%	9.5%
	Net Sharpe Ratio	0.29	0.33	0.32	0.30	0.31	0.31	0.31
	Vol of Realized Volatility*	2.5%	2.2%	2.2%	2.3%	2.2%	2.2%	2.3%
	Max Drawdown	-35.8%	-27.8%	-28.5%	-30.9%	-30.7%	-30.9%	-30.9%
Turnover	Annual Turnover	0.0%	3.6%	6.7%	19.3%	5.7%	8.2%	11.5%
	Avg # Rebals / Year	0.0	0.5	1.0	12.0	0.5	1.0	2.4
	Avg Trade Size	N/A	7.3%	6.7%	1.6%	12.2%	8.4%	4.8%
	Annual Trade Cost*	0.00%	0.02%	0.03%	0.10%	0.03%	0.04%	0.06%

B. Impact of Degree

	Impact of Degree	Buy and Hold	Annual Rebalance			Monthly Rebalance		
			25%	50%	100%	25%	50%	100%
Ex Ante	Avg Allocation Range*	73%	59%	51%	47%	26%	20%	21%
	Vol of Ex Ante Volatility*	2.4%	2.2%	2.2%	2.3%	2.3%	2.3%	2.3%
Performance	Net Total Return	8.7%	8.8%	8.8%	8.8%	8.7%	8.7%	8.7%
	Volatility	10.0%	9.5%	9.4%	9.4%	9.4%	9.4%	9.5%
	Net Sharpe Ratio	0.29	0.31	0.32	0.32	0.31	0.31	0.30
	Vol of Realized Volatility*	2.5%	2.3%	2.2%	2.2%	2.2%	2.2%	2.3%
	Max Drawdown	-35.8%	-28.2%	-28.0%	-28.5%	-30.0%	-30.7%	-30.9%
Turnover	Annual Turnover	0.0%	2.0%	3.6%	6.7%	8.0%	11.6%	19.3%
	Avg # Rebals / Year	0.0	1.0	1.0	1.0	12.0	12.0	12.0
	Avg Trade Size	N/A	2.0%	3.6%	6.7%	0.7%	1.0%	1.6%
	Annual Trade Cost*	0.00%	0.01%	0.02%	0.03%	0.04%	0.06%	0.10%

Source: AQR. "Avg alloc range" is [(Max-min allocation) / target allocation], averaged across asset classes. "Vol of ex ante vol" is volatility of ex ante volatility based on rolling 36-month covariance matrix. Gross total return is annualized arithmetic rate of return. Returns and Sharpe ratios are net of estimated transaction costs from rebalancing, gross of fees. Risk-free rate is 3-month T-Bill rate. "Vol of realized vol" is volatility of rolling 36-month volatility. Annual trade cost assumes uniform transaction cost of 0.5% for all asset classes. Allocations are as described in Exhibit 2. Hypothetical data has inherent limitations. some of which are disclosed herein.

[15] Represented by the MSCI U.S. Index and the Barclays Intermediate Treasury Index respectively.

attempt to give each asset class a roughly equal probability of triggering a rebalance. For example, to calculate tolerance bands for the +/-20% strategy, we multiply by 20% the average of the asset's target allocation (relative component) and the average target allocation across all assets (absolute component). Then we average this with a volatility-adjusted equivalent.

Varying Tolerance Bands

Exhibit A2 shows the impact of varying the trigger threshold on various portfolio characteristics. Widening thresholds reduces costs but permits wider ranges of allocations, while over this period returns and Sharpe ratios are unchanged. Partial rebalancing reduces costs with little impact on allocation ranges. Compared to a fixed annual rebalance, half rebalancing with +/-30% thresholds gives both tighter allocations and lower costs. However, as mentioned previously, the price-agnostic calendar-based schedule appears to better capture momentum effects (higher return and Sharpe ratio).

Exhibit A2: Impact of Varying Rebalance Triggers 1972-2014

Full Rebalance	Fixed 1M	Trigger Threshold 10%	20%	30%	40%	Fixed 1Y
Avg Allocation Range*	27%	35%	52%	67%	80%	68%
Vol of Ex Ante Vol*	2.0%	2.0%	2.0%	2.0%	2.1%	2.0%
Net Total Return	9.0%	9.0%	9.1%	9.1%	9.1%	9.3%
Volatility	8.1%	8.1%	8.2%	8.3%	8.3%	8.0%
Net Sharpe Ratio	0.39	0.40	0.40	0.40	0.40	0.43
Annual Trade Cost*	0.13%	0.07%	0.05%	0.03%	0.03%	0.05%

Half Rebalance	Fixed 1M	Trigger Threshold 10%	20%	30%	40%	Fixed 1Y
Avg Allocation Range*	34%	38%	54%	66%	82%	85%
Vol of Ex Ante Vol*	2.0%	2.0%	2.0%	2.1%	2.1%	1.9%
Net Total Return	9.0%	9.1%	9.1%	9.1%	9.1%	9.3%
Volatility	8.1%	8.1%	8.1%	8.3%	8.4%	8.0%
Net Sharpe Ratio	0.40	0.40	0.40	0.40	0.40	0.43
Annual Trade Cost*	0.08%	0.05%	0.03%	0.02%	0.02%	0.03%

Source: AQR. "Avg allocation range" is [(Max-min allocation) / target allocation], averaged across asset classes. "Vol of ex ante vol" is volatility of ex ante volatility based on rolling 36-month covariance matrix. Returns and Sharpe ratios are net of estimated transaction costs from rebalancing, gross of fees. Risk-free rate is 3-month T-Bill rate. Annual trade cost assumes uniform transaction cost of 0.5% for all asset classes. Allocations are as described in Exhibit 2.

Timing of Trigger-Based Rebalances

Exhibit A3 shows the dates of rebalances for one version of the strategy: +/-30% full rebalancing. It also shows past 12-month total returns for each asset class on each rebalance date. Highlighted cells have 12-month excess return exceeding average +1 stdev (green) or worse than average -1 stdev (red), based on full-period average and volatility. It is clear that rebalances tend to be triggered after abnormally high or low returns for one or more asset classes. Trigger-based rebalance trades are therefore more likely to contradict time series momentum signals than price-agnostic calendar-based trades, which may explain why the latter process outperforms in our analysis.

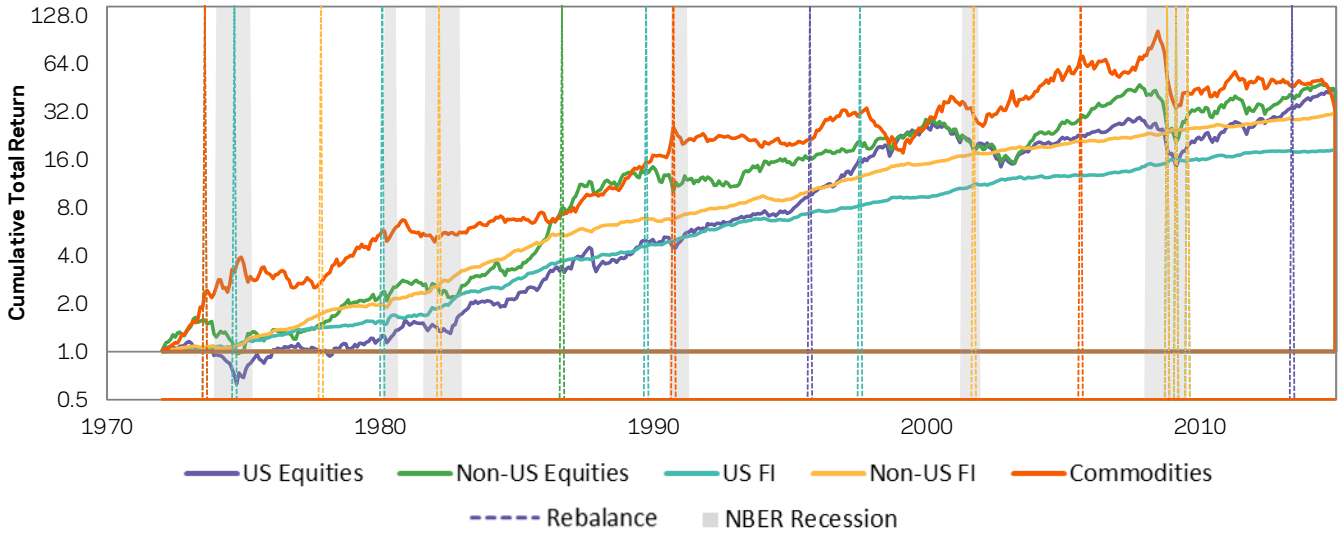
Exhibit A3: Asset Class Past 12-Month Total Return at Each Rebalance for +/-30% Full Rebalance Strategy, 1972-2014

	Trigger Date	US Equities	Non-US Equities	US FI	Non-US FI	Commodities
1	Jul-73	0.7%	20.4%	-1.0%	2.2%	108.9%
2	Aug-74	-30.4%	-30.5%	3.9%	-0.2%	29.6%
3	Oct-77	-7.8%	24.5%	4.9%	22.9%	8.1%
4	Jan-80	14.1%	15.3%	4.3%	2.9%	34.8%
5	Feb-82	-10.1%	-8.9%	13.8%	17.1%	-8.3%
6	Aug-86	37.2%	93.7%	18.8%	15.3%	15.5%
7	Sep-89	31.4%	22.5%	9.6%	7.6%	50.8%
8	Sep-90	-9.5%	-27.0%	8.5%	-1.8%	65.9%
9	Sep-95	29.7%	5.8%	10.6%	14.3%	6.1%
10	Jul-97	52.1%	19.1%	8.5%	13.9%	10.9%
11	Sep-01	-27.2%	-29.1%	12.4%	9.2%	-17.4%
12	Aug-05	12.6%	24.8%	1.9%	7.6%	42.6%
13	Oct-08	-36.6%	-46.5%	8.4%	4.6%	-24.9%
14	Feb-09	-43.5%	-50.3%	5.2%	5.0%	-58.1%
15	Jul-09	-20.7%	-22.4%	5.9%	7.8%	-53.1%
16	May-13	26.3%	29.6%	0.0%	3.3%	3.3%

Source: AQR. Highlighted cells have 12-month excess return exceeding average +1 stdev (green) or worse than average -1 stdev (red), based on full-period average and volatility. Please see Exhibit 2 for portfolio constituents.

Finally, **Exhibit A4** illustrates the timing of these rebalances on a graph of cumulative asset returns.

Exhibit A4: Cumulative Gross Returns and Hypothetical Rebalance Triggers (+/-30% Full Rebalance)



Source: AQR. Please see Exhibit 2 for portfolio constituents. Hypothetical data has inherent limitations, some of which are disclosed herein.

References

Ang, Andrew, 2014, "Asset Management: A Systematic Approach to Factor Investing," OUP.

AQR *Alternative Thinking*, 4Q 2014, "Challenges of Incorporating Tactical Views."

Gort, Christoph, and E. Burgener, 2014, "Rebalancing Using Options," working paper.

Harvey, Campbell R., N. Granger, D. Greenig, S. Rattray and D. Zou, 2014, "Rebalancing Risk," working paper.

Hurst, Brian, Y.H. Ooi, and L. Pedersen, 2012, "A Century of Evidence on Trend-Following Investing," AQR White Paper.

Moskowitz, T., Y.H. Ooi, and L. Pedersen, 2012, "Time Series Momentum," *The Journal of Financial Economics*, 104(2), 228–250.

NBIM Discussion Note, 2012, "Empirical analysis of rebalancing strategies."

Qian, Edward, 2014, "To Rebalance or Not to Rebalance: A Statistical Comparison of Terminal Wealth of Fixed-Weight and Buy-and-Hold Portfolios," working paper.

Sharpe, William F., 2010, "Adaptive Asset Allocation Policies," *Financial Analysts Journal*, 66(3), 45-59.

Sun, Walter, A. Fan, L. Chen, T. Schouwenaars, and M.A. Albota, 2006, "Optimal Rebalancing for Institutional Portfolios," *The Journal of Portfolio Management*, 32(2), 33-43.

The information set forth has been obtained or derived from sources believed by the authors and AQR Capital Management, LLC ("AQR") to be reliable. However the authors and AQR do not make any representation or warranty, express or implied, as to the information's accuracy or completeness, nor does AQR recommend that the attached information serve as the basis of any investment decision. This document has been provided to you for information purposes and does not constitute an offer or solicitation of an offer, or any advice or recommendation, to purchase any securities or other financial instruments, and may not be construed as such. This document is intended exclusively for the use of the person to whom it has been delivered by AQR and it is not to be reproduced or redistributed to any other person. This document has been prepared solely for information purposes. The information contained herein is only current as of the date indicated, and may be superseded by subsequent market events or for other reasons. Charts and graphs provided herein are for illustrative purposes only. Nothing contained herein constitutes investment, legal tax or other advice nor is it to be relied on in making an investment or other decision.

There can be no assurance that an investment strategy will be successful. Historic market trends are not reliable indicators of actual future market behavior or future performance of any particular investment which may differ materially, and should not be relied upon as such.

The information in this document may contain projections or other forward-looking statements regarding future events, targets, forecasts or expectations regarding the strategies described herein, and is only current as of the date indicated. There is no assurance that such events or targets will be achieved, and may be significantly different from that shown here. The information in this presentation, including statements concerning financial market trends, is based on current market conditions, which will fluctuate and may be superseded by subsequent market events or for other reasons. Performance of all cited indices is calculated on a total return basis with dividends reinvested. The indices do not include any expenses, fees or charges and are unmanaged and should not be considered investments.

The investment strategy and themes discussed herein may be unsuitable for investors depending on their specific investment objectives and financial situation. Please note that changes in the rate of exchange of a currency may affect the value, price or income of an investment adversely.

Neither AQR nor the authors assumes any duty to, nor undertakes to update forward looking statements. No representation or warranty, express or implied, is made or given by or on behalf of AQR, the authors or any other person as to the accuracy and completeness or fairness of the information contained in this presentation, and no responsibility or liability is accepted for any such information. By accepting this document in its entirety, the recipient acknowledges its understanding and acceptance of the foregoing statement.

Diversification does not eliminate the risk of experiencing investment losses.

There is no guarantee, express or implied, that long-term return and/or volatility targets will be achieved. Realized returns and/or volatility may come in higher or lower than expected. PAST PERFORMANCE IS NOT AN INDICATION OF FUTURE PERFORMANCE.

Simulated I performance results (e.g., quantitative backtests) have many inherent limitations, some of which, but not all, are described herein. No representation is being made that any fund or account will or is likely to achieve profits or losses similar to those shown herein. In fact, there are frequently sharp differences between hypothetical performance results and the actual results subsequently realized by any particular trading program. One of the limitations of simulated results is that they are generally prepared with the benefit of hindsight. In addition, simulated trading does not involve financial risk, and no hypothetical trading record can completely account for the impact of financial risk in actual trading. For example, the ability to withstand losses or adhere to a particular trading program in spite of trading losses are material points which can adversely affect actual trading results. The simulated results contained herein represent the application of the quantitative models as currently in effect on the date first written above and there can be no assurance that the models will remain the same in the future or that an application of the current models in the future will produce similar results because the relevant market and economic conditions that prevailed during the hypothetical performance period will not necessarily recur. There are numerous other factors related to the markets in general or to the implementation of any specific trading program which cannot be fully accounted for in the preparation of hypothetical performance results, all of which can adversely affect actual trading results. Discounting factors may be applied to reduce suspected anomalies. This backtest's return, for this period, may vary depending on the date it is run. Simulated performance results are presented for illustrative purposes only.

There is a risk of substantial loss associated with trading commodities, futures, options, derivatives and other financial instruments. Before trading, investors should carefully consider their financial position and risk tolerance to determine if the proposed trading style is appropriate. Investors should realize that when trading futures, commodities, options, derivatives and other financial instruments one could lose the full balance of their account. It is also possible to lose more than the initial deposit when trading derivatives or using leverage. All funds committed to such a trading strategy should be purely risk capital.

AQR Capital Management, LLC
Two Greenwich Plaza, Greenwich, CT 06830
p: +1.203.742.3600 | f: +1.203.742.3100 | w: aqr.com