Energy entropy

Equity Quantitative Research

September 2018

How can the energy component improve risk-adjusted returns

Executive Summary

- Rebalancing has become more than a risk management technique—it can be used to deliver alpha. When evaluating the extensive research on rebalancing as a source of alpha, it is important to be vigilant of possible shortcomings leading to skewed results.
- By examining the different families of alternative-weighting schemes, we are able to determine a robust methodology to capture the rebalancing premium.
- The “energy entropy” framework can help analyze the impact of portfolio rebalancing, with an emphasis on benefitting from market volatility. By leveraging the results from this framework, we can evaluate indices and their ability to capture the positive drift from the market.

HSBC Global Asset Management

Introduction

In general, portfolio rebalancing is the action required to re-align portfolio weights to a new set of views, which satisfy the investor's risk and return preferences. In its simplest form, rebalancing is triggered based on a set time schedule such as monthly, quarterly, semi-annually etc. and the new weights can be the original weights that were chosen at the beginning of the investment period.

As different assets generate different returns, the portfolio's asset composition will deviate from the target weights over time. In order to remain consistent with the investor's initial targets, the portfolio needs to be rebalanced back to the predefined weights. In long-only portfolios, this implies selling a fraction of the better-performing assets and investing the proceeds in the worse performing. As a result, rebalancing is a countercyclical strategy that systematically "buys low and sells high" and, therefore, can be thought as a type of a "value investing strategy." If no rebalancing takes place, then the only change in the initial weights is due to the relative returns of the component assets. This drift in the weights causes the portfolio to become concentrated over time and be dominated by the stocks in the portfolio that perform well. This is a buy-and-hold strategy. An example of such a strategy is the market-cap index, although, in practice, some rebalancing takes place when some low-return stocks are replaced by others.

Although rebalancing was primarily seen as a risk management vehicle which helps the investor avoid deviating from his risk exposure targets, since the 80's portfolio rebalancing has also caught the attention of many academics and practitioners as a source of alpha. Since fundamental indices have become very popular, many attempts have been made to illustrate the benefits of rebalancing effects, giving rise to a vast literature trying to investigate and quantify the added value of a rebalancing strategy compared to a buy-and-hold one. The existing literature is controversial with contradictory conclusions.

In this paper we summarize the existing literature on the rebalancing premium, introduce an innovative way of thinking about alternative-weighting schemes and, finally, refer to a new theoretical framework, the energy entropy framework, developed by two mathematicians at the University of Washington, Soumik Pal and Ting-Kam Leonard Wong, in order to interpret results, with the belief that we can develop fundamental indices which can capture rebalancing effect in a pure way.

Basic literature review

"In an equity-bond portfolio, momentum favors the buy and hold strategy whereas rebalancing benefits from market reversals"

Sharpe & Perold (1988)

"The optimal environment for extracting a positive rebalancing premium is to have high volatilities, low correlation but also returns in the long run need to be roughly similar"

Bernstein (1997)

"In a cash-stock portfolio where assets have the same growth rate, a buy and hold portfolio does not enjoy the excess growth which occurs in a rebalanced one. Rebalancing is an infinitesimal version of buying low and selling high – excess growth stems from the accrual revenues produced by the price fluctuations"

Fernholz & Shay (1982)

"As it is possible to harness energy from the waves in the ocean, it is possible to harvest return from volatility in the market. There is extra return from diversification due to reweighting the portfolios' long term exposures and extra return from rebalancing which constantly buys low and sells high"

Bouchey, Nemtchicov, Paulsen and Stein (2012)

"Rebalancing cannot generate excess growth and hence greater terminal wealth than buy and hold, without negative autocorrelation in relative assets returns. Rebalancing is worthwhile to the extent that it stops the portfolio variance from rising because the portfolio becomes more concentrated in the best performing assets"

Cuthbertson, Hayley, Motson, Nitzche (2015)

What should we consider when replicating previous results?

Most of the prior research in portfolio rebalancing is based on either:

- Investigating a single investment period and for specific asset allocations (e.g., an equally-weighted portfolio of stocks or a fixed allocation between a stock and a bond index), or
- Monte Carlo-simulated asset returns (where the simulation parameters are assumed and not calibrated "on" market data)

With papers that only investigate a specific investment period, they may intensify the potential problem of data snooping and lead to misleading results. This can be shown by the example in Figure 1.

Assume the MSCI ACWI for the period of January 2000 to January 2018. We construct 1,000 random portfolios of 50 stocks and compare the performance of a rebalanced strategy (RB) and its corresponding buy-and-hold (BH) for an equal-weighting scheme (EQW) as well as a weighting scheme that is tilted more towards small-cap stocks over two sample periods within this range.

If the historical analysis investigates a single realization or a fairly small number of realizations, then it is possible that the return observations are more influenced by specific characteristics of the underlying sample periods, rather than properties of the rebalancing and buy-and-hold strategies under investigation.

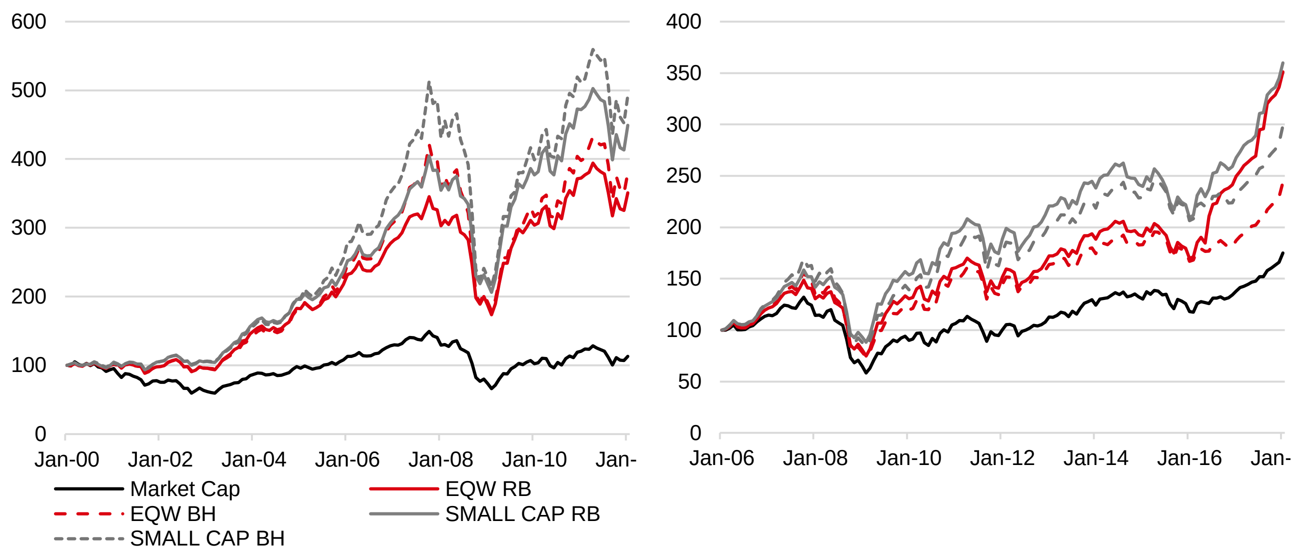
It is crucial to make the comparison of the strategies on a statistical basis and, in order to do so, we need to increase the number of the possible realizations of the stock returns. There are three main ways to achieve this:

1. Monte Carlo Simulation
2. Block Bootstrapping
3. Rolling Window

The limitations of a Monte Carlo simulation depend not only on the choice of the model under which the returns will evolve, but also on the complexity of its calibration. When the models are calibrated to market prices, we still find that the supposed constant parameters in the model keep changing. Although block bootstrapping looks promising, in order to have a stationary resample, the block size needs to be random and the choice of its length is hard to estimate. However, a rolling window approach preserves the time series characteristics and enables the analysis of all the investment horizons of a particular length that have been realized under the underlying sample period.

Figure 1: 50 stock back-test / 2000-2012

50 stock back-test / 2006-2018



Source: HSBC Global Asset Management, Thompson Reuters, January 31, 2000 – January 31, 2018. Back-tested results have inherent limitations, some of which are described below. Backtested returns do not represent the performance results of actual trading or portfolio asset allocations for any client assets or portfolios. Back-tested returns are calculated through the retroactive application of the proposed asset allocation to its relevant benchmark and are produced with the benefit of hindsight. Therefore, the performance results are not indicative of the skill of HSBC Global Asset Management or of future results. Since back-tested performance results do not represent actual trading or portfolio asset allocations they may not reflect the impact that material economic and market factors might have had on decisions made in actual trading or portfolio asset allocations. No representation is being made that any portfolio will or is likely to achieve profits or losses similar to those shown. In fact, there are frequently significant material differences between back-tested performance and performance results subsequently achieved by following a particular strategy.

A new way to think about Alternative-Weighting Schemes (AWS)

A conventional approach is to look at the risk characteristics of alternative-weighting schemes. We consider four "families" of AWS:

1. Equal: equally-weighted to all stocks
2. Large-Cap: tilted towards high-ranked stocks
3. Mid-Cap: tilted towards stocks that are in the middle of the ranking
4. Small-Cap: tilted towards stocks that have a low ranking

Potentially all AWS can be expressed in terms of these families.

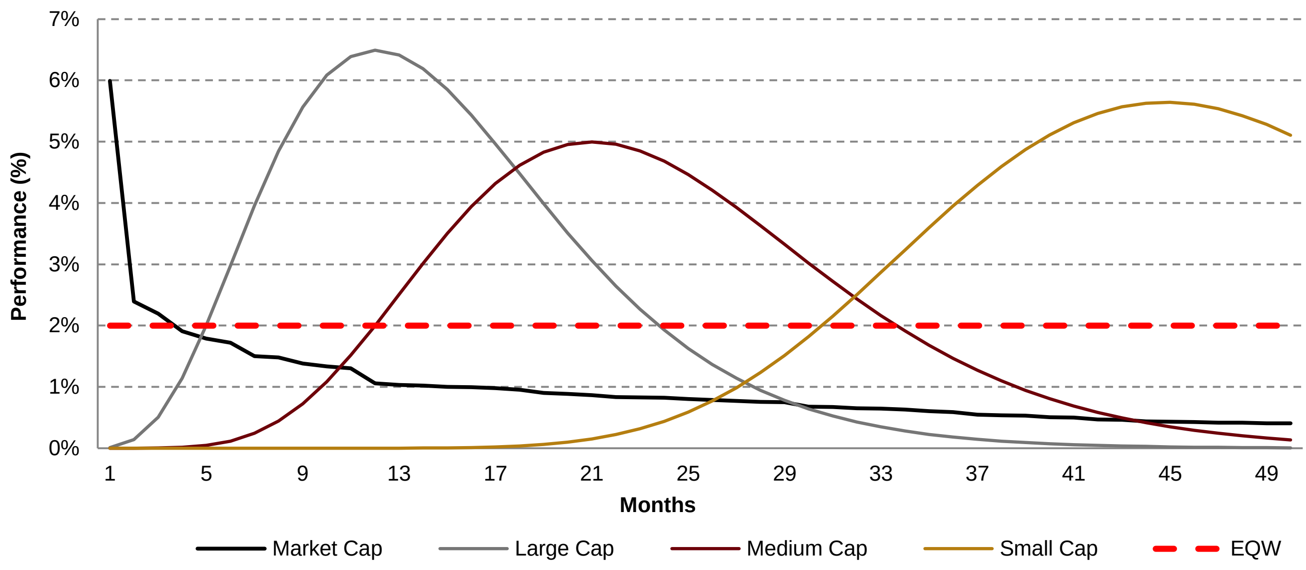
The main point we want to understand is whether one of these families can exhibit more robust capture of the rebalancing effect. To do this, we compare the performance of semi-annual RB to BH for different portfolio sizes of stocks which were picked randomly from the MSCI ACWI for the weighting schemes described (Figure 2).

We assume holding periods of different lengths (1, 3, 5, … 15 years). For each of these, we create rolling window samples from the historical monthly data of the sample period January 2001 to January 2015. For each rolling window sample, 2,000 portfolios of size N = 50, 200, 500 and 1000 are constructed. The N stocks are picked each time randomly from MSCI ACWI in order for the performance not to be skewed by the stock selection.

Following Bouchet et al. (2012)[1], we use the rebalancing premium, which is captured by the difference between the annualized return of a RB strategy and its corresponding BH as a performance metric. If positive, then RB outperforms BH. This performance metric is calculated for all 2,000 portfolios and then the mean is taken. We repeat the previous step for all rolling window samples in a given holding period and then we take the mean across them.

From the following charts (Figures 3 and 4), we see that large cap-weighting schemes exhibit more robust results, regardless of the portfolio size. This can be justified by the fact that they are more consistent with the benchmark whereas EQW, small cap-weighting and medium cap-weighting are more exposed to small-cap stocks.

Figure 2: Different weighting schemes for stocks ranked by their market capitalization



Source: HSBC Global Asset Management, December 31, 2017.

Simulated data is shown for illustrative purposes only, and should not be relied on as indication for future returns. Simulations are based on Back Testing assuming that the optimisation models and rules in place today are applied to historical data. As with any mathematical model that calculates results from inputs, results may vary significantly according to the values inputted. Prospective investors should understand the assumptions and evaluate whether they are appropriate for their purposes. Some relevant events or conditions may not have been considered in the assumptions. Actual events or conditions may differ materially from assumptions.

[1] *Bouchet, Nemtchinov, Paulsen and Stein (2012): "Volatility Harvesting: Why does Diversifying and Rebalancing Create Portfolio Growth?"*

Figure 3: Rebalancing Premium (RB-BH) : annual returns

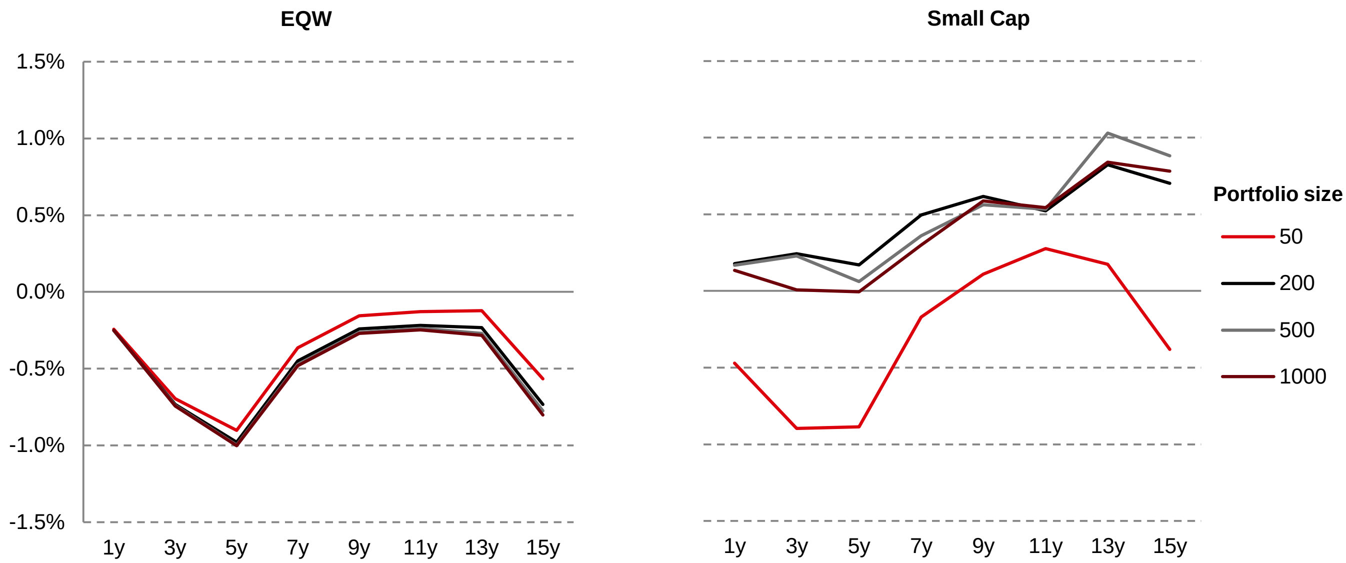
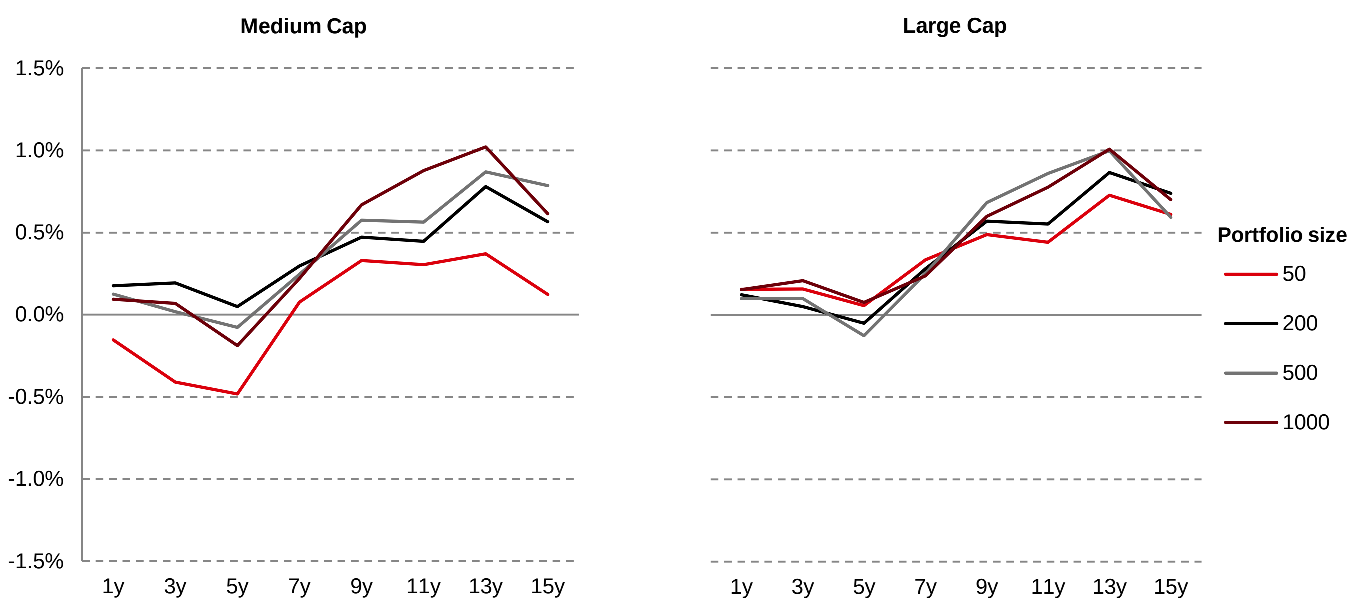


Figure 4: Rebalancing Premium (RB-BH): annual returns



Source: HSBC Global Asset Management, Thompson Reuters, January 31, 2001 – January 31, 2016. Back-tested results have inherent limitations, some of which are described below. Backtested returns do not represent the performance results of actual trading or portfolio asset allocations for any client assets or portfolios. Back-tested returns are calculated through the retroactive application of the proposed asset allocation to its relevant benchmark and are produced with the benefit of hindsight. Therefore, the performance results are not indicative of the skill of HSBC Global Asset Management or of future results. Since back-tested performance results do not represent actual trading or portfolio asset allocations they may not reflect the impact that material economic and market factors might have had on decisions made in actual trading or portfolio asset allocations. No representation is being made that any portfolio will or is likely to achieve profits or losses similar to those shown. In fact, there are frequently significant material differences between back-tested performance and performance results subsequently achieved by following a particular strategy.

Energy-Entropy Decomposition – A more robust theoretical framework

We now wish to explore the results in a more robust theoretical framework. Pal and Wong (2013, 2016) introduced an information-theoretic, path-wise and model-free framework for analyzing the performance of any portfolio relative to the market (buy-and-hold) portfolio, with an emphasis on profiting from market volatility. Under this framework, the long-term return of the relative portfolio (RB over BH) is decomposed in three terms:

1. a relative entropy term that measures the distance between the portfolio holdings and the market capital distribution.
2. an entropy term that can be controlled by the trader by choosing a suitable strategy.
3. a term that can be interpreted as (free) energy coming from the market fluctuations (i.e. volatility-driven relative returns).

To make things clear, assume a long-only portfolio consisting of N stocks. Since no short-selling is allowed, the portfolio weights can be thought of as a probability distribution. Let $V_\mu(t)$ be the value of the BH portfolio with weights $\{\mu_i(t)\}_{i=1}^N$. Given any portfolio strategy $\{\pi_i(t)\}_{i=1}^N$ with value $V_\pi(t)$, the relative log return of the portfolio $V(t) = \frac{V_\pi(t)}{V_\mu(t)}$ can be expressed as:

$$\Delta \log V(t) = \sum_{i=1}^{N} \pi_i(t) \log \frac{\mu_i(t+1)}{\mu_i(t)} + \gamma_\pi^*(t) \quad (1)$$

where $\gamma_{\boldsymbol{\pi}}^*(t)$ can be viewed as a measure of cross-sectional volatility of the market. In the limit, it becomes the excess growth rate introduced by Fernholz and Shay.[2] The distance between the portfolio and market weights can be measured in terms of relative entropy:

$$D(\boldsymbol{\pi}||\boldsymbol{\mu}) = -\sum_{i=1}^{N} \pi_i \log \frac{\mu_i}{\pi_i}$$

By using the relative entropy definition, we can rewrite (1) as follows:

$$\Delta \log \mathrm{V(t)} = -\big(D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) - D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t))\big) + \big(D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) - D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t+1))\big) + \gamma_\pi^*(t)$$

$$\Rightarrow \Delta \log \mathrm{V(t)} = -\,\Delta\mathrm{relativeEntropy} + \Delta\mathrm{control} + \Delta\mathrm{energy}$$

Intuitively, we think that the market offers a constant amount of volatility (Δenergy). Under suitable market conditions, it can be captured and turned into profit by a dynamic rebalancing strategy. By construction it will increase with time, thus Δenergy > 0. The relative entropy term monitors the distance between the portfolio weight and the market weight vectors.

[2] *Fernholz and Shay (1982): "Stochastic portfolio theory and stock market equilibrium"*

We have the following interpretation depending on the sign:

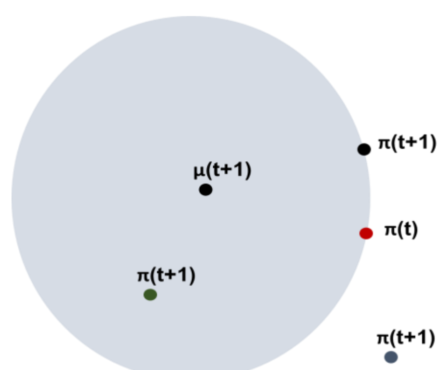
- $\Delta\mathrm{relativeEntropy} > 0 \Rightarrow D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) > D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t))$, at $t+1$ the distance between the portfolio and the market is bigger than it was at t.
- $\Delta\mathrm{relativeEntropy} < 0 \Rightarrow D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) < D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t))$, at $t+1$ the distance between the portfolio and the market is smaller than it was at t.
- $\Delta\mathrm{relativeEntropy} = 0 \Rightarrow D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) = D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t))$, at $t+1$ the distance between the portfolio and the market is the same as it was at t.

The control term is determined by the new portfolio weight vector $\boldsymbol{\pi}(t+1)$ chosen at time $t+1$. Since it depends on the action of the investor, we call it the control term. Assume that the portfolio is currently at $\boldsymbol{\pi}(t)$ (red dot in Figure 5) and at the next step, the market moves to $\boldsymbol{\mu}(t+1)$. The circle around $\boldsymbol{\mu}(t+1)$ defines all portfolios that have the same distance from the market ($D(.||\boldsymbol{\mu}(t+1)) = c$))

We have the following interpretation according to the sign:

- $\Delta\mathrm{control} > 0 \Rightarrow D(\boldsymbol{\pi}(t+1)||\boldsymbol{\mu}(t+1)) > D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t$

Figure 5: Representation of the evolution in portfolio weights under different $\boldsymbol{\Delta}$control values



Source: HSBC Global Asset Management, December 31, 2017. For illustrative purposes only

Interpretation of rebalancing under the Energy-Entropy framework

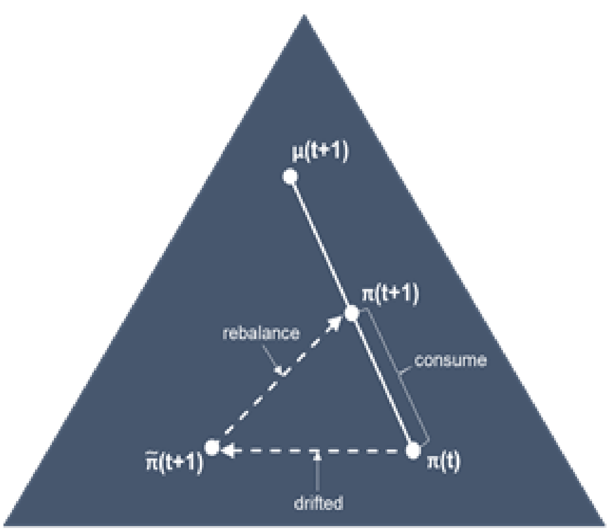
Most strategies, including constant-weighted portfolios, maintain the desired portfolio weights through rebalancing. If at time t the portfolio vector is $\boldsymbol{\pi}(t)$, then just before the trading that happens at $t+1$, the weight of stock i with return $R_i(t)$ over the interval $[t, t+1]$ is given by:

$$\tilde{\pi}_i(t+1) = \frac{\pi_i(t)(1 + R_i(t))}{\sum_{i=1}^{N} \pi_i(t)(1 + R_i(t))}$$

Properly speaking, rebalancing is the trading that moves the portfolio weights from $\tilde{\boldsymbol{\pi}}(t+1)$ to $\boldsymbol{\pi}(t+1)$ and not from $\boldsymbol{\pi}(t)$ to $\boldsymbol{\pi}(t+1)$. With this terminology, the control term will never be zero, even for the case of the constant-weighted portfolio.

A positive control term suggests moving away from the market weights at every step. A less-risky strategy would be to choose a negative control term so that $\boldsymbol{\pi}(t+1)$ will be closer to $\boldsymbol{\mu}(t+1)$ than $\tilde{\boldsymbol{\pi}}(t+1)$ was. In energy-entropy terms, the free energy is thought of as available market resources, part of which can be *consumed* by the control term in order to bring the portfolio closer to the market.

Figure 6: The consumption of energy involved in bringing a portfolio closer to the market



Source: Pal and Wong (2013, 2016): "Energy, Entropy and Arbitrage". For illustrative purposes only

Energy-Entropy portfolios

Assume again the energy-entropy decomposition:

$$\Delta \log V(t) = \Delta\text{energy} - \Delta\text{relativeEntropy} + \Delta\text{control}$$

$$\Rightarrow \sum \Delta \log V(t) = \sum \Delta\text{energy} + \Delta\text{control} - \sum \Delta\text{relativeEntropy}$$

$$\Rightarrow \log V(t) = \sum \Delta\text{energy} + \Delta\text{control} - \left[D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t)) - D(\boldsymbol{\pi}(0)||\boldsymbol{\mu}(0))\right]$$

Intuitively, $\Delta\text{energy} + \Delta\text{control}$ can be thought as the "leftover" energy after rebalancing and the purpose of such rebalancing is to control the relative entropy distance. We will define an energy-entropy portfolio as the strategy $\boldsymbol{\pi}$ which satisfies:

$$\Delta\text{Drift}(t) = \Delta\text{energy}(t) + \Delta\text{control}(t) \geq 0, t \geq 0$$

As long as the drift process grows faster than the relative entropy distance $D(\boldsymbol{\pi}(t)||\boldsymbol{\mu}(t))$ between the portfolio and market weights, the energy-entropy portfolio eventually outperforms the market.

Empirical Results

We assume monthly data of the period July 2007 and January 2018 and analyze the performance in energy-entropy terms of the following indices over the MSCI World index (MXWO):

- RAFI Develop Index (RAFI DEV) – commercial fundamental index. FTSE partners with Research Affiliates® on the FTSE RAFI™ Index Series. Index constituents are weighted using a composite of fundamental factors, including total cash dividends, free cash flow, total sales and book equity value. Prices and market values are not determinants of the index weights
- Economic Scale Developed Equity (ESE DEV) - Theoretical rule-based index aiming to provide investors with a broad equity exposure by weighting firms based on the economic contribution that they make to the global economy.

The outperformance of ESE DEV (Figure 7) during this period is a result of the following:

1. ESE DEV weights are able to capture higher amounts of free energy during this period (Figure 8).
2. ESE DEV tries to keep a stable distance from the market, keeping its relative entropy in positive levels (Figure 9). As a result, the control term is moving with a slower pace towards negative values, compared to the control term of RAFI DEV (Figure 10). Therefore, the amount of free energy that ESE DEV consumes in order to keep track of the market is less than RAFI DEV consumes.
3. ESE DEV captures more free energy than RAFI DEV, while spending less on control and therefore delivering a higher drift (Figure 11).

Figure 7: Relative portfolios backtests

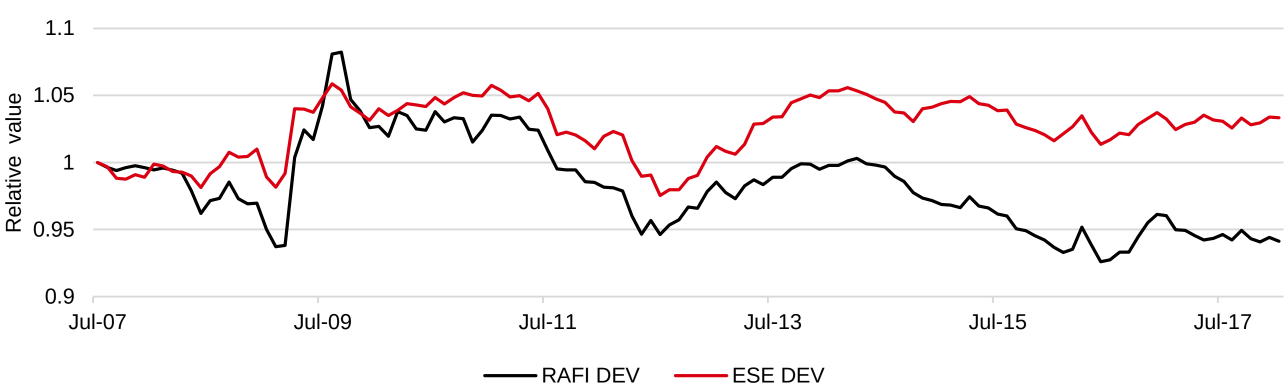


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Figure 8: Free energy

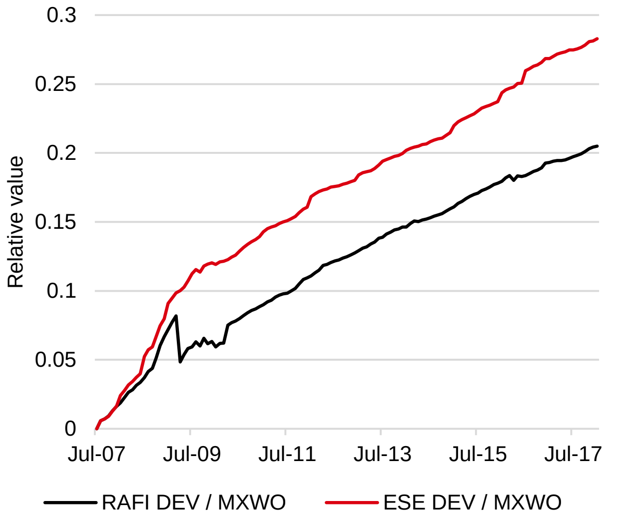


Figure 9: Relative entropy

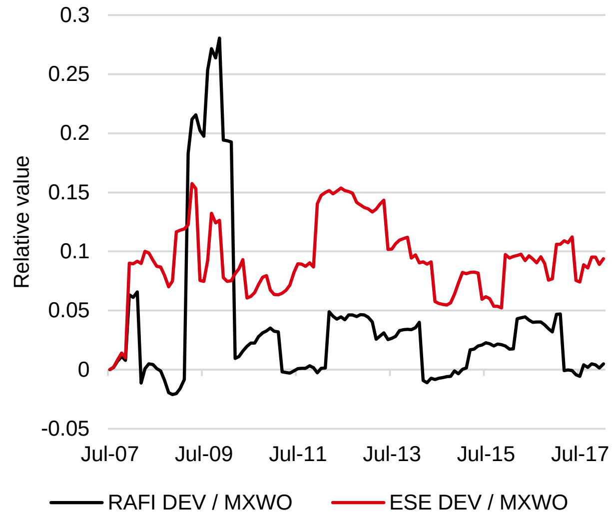


Figure 10: Control

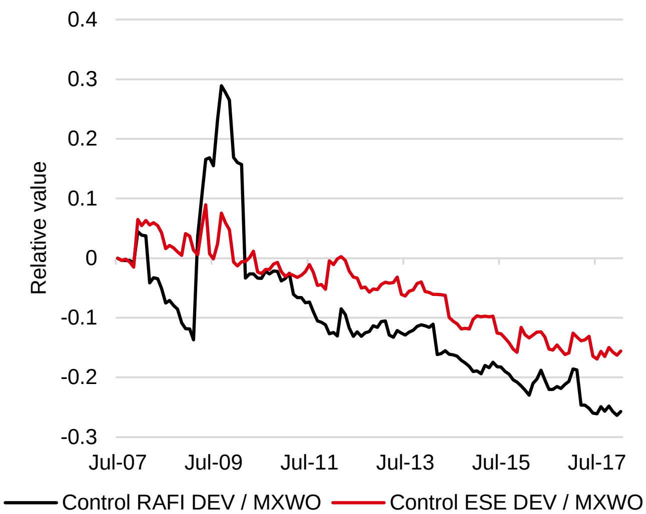
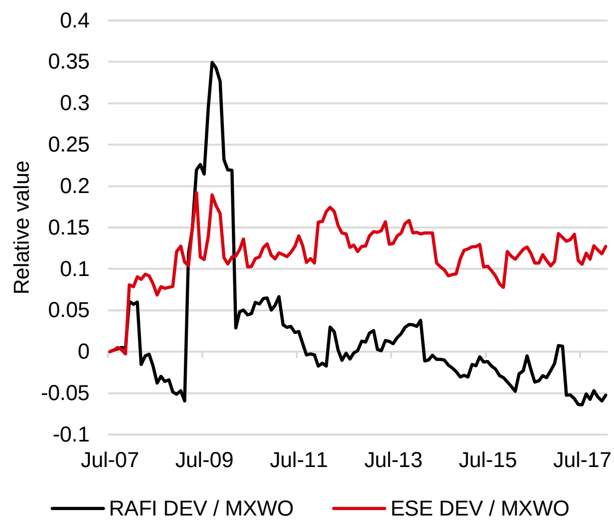


Figure 11: Drift



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Conclusion

Fundamental indices have become very popular and many attempts have been made to illustrate the benefits of rebalancing effects. The existing literature is controversial with contradictory conclusions. Attempts to formulate the rebalancing premium are based on differential stochastic calculus, under the assumption of continuous rebalancing. On the other hand, empirical results are derived by either investigating specific investment horizons or carrying out Monte Carlo simulations.

Continuous rebalancing is impossible. Real-world portfolios can be rebalanced only at finite intervals. Furthermore, if the historical analysis investigates a single realization or a fairly small number of realizations, then it is possible that the return observations are more influenced by specific characteristics of the underlying sample period than properties of the RB and BH strategies under investigation. In order to increase the number of possible realizations, Monte Carlo simulations and block bootstrapping are often used, but again the market dynamics cannot be captured to the full.

The energy-entropy framework introduced by Pal and Wong[3] is path-wise and completely free of stochastic modelling assumptions and separates the problem of rebalancing in two parts:

1. the path properties required for rebalancing to be profitable and
2. whether these conditions are satisfied by the actual market over the investment horizon.

Previous approaches tend to consider both questions together and give mixed results depending on the data used. Under the energy-entropy framework, the long-run log-return of a portfolio relative to the market is expressed in terms of the excess growth and decomposed in three components:

1. a component that can be interpreted as (free) energy coming from the market volatility,
2. a relative entropy component that measures the distance between the rebalancing strategy and the market cap index and
3. an entropy component that can be controlled by the trader by choosing the portfolio weights on the rebalancing date.

The energy component aids the growth in the portfolio value by improving risk-adjusted returns while the relative entropy component describes risk, which, in some ways, is analogous to tracking-error type measures. When relative entropy moves towards positive values, the distance from the market increases and when it moves towards negative values, the distance decreases. It follows that an ideal strategy stays close to the benchmark all the while continuously capturing the free energy, which is positive by construction (we rebalance to benefit from volatility).

From the empirical results, we can see that ESE DEV not only manages to capture more free energy than RAFI DEV, but also does this while being closer to the market. This can be interpreted as a portfolio with smaller style biases. This means that ESE DEV more consistently captures the positive drift from rebalancing.

[3] *Pal and Wong (2013,2016): "Energy, Entropy and Arbitrage"*

Key risks

The value of an investment in the portfolios and any income from them can go down as well as up and as with any investment you may not receive back the amount originally invested.

- Exchange rate risk: Investing in assets denominated in a currency other than that of the investor's own currency perspective exposes the value of the investment to exchange rate fluctuations.
- Derivative risk: The value of derivative contracts is dependent upon the performance of an underlying asset. A small movement in the value of the underlying can cause a large movement in the value of the derivative. Unlike exchange traded derivatives, over-the-counter (OTC) derivatives have credit risk associated with the counterparty or institution facilitating the trade.
- Emerging market risk: Emerging economies typically exhibit higher levels of investment risk. Markets are not always well regulated or efficient and investments can be affected by reduced liquidity.
- Operational risk: The main risks are related to systems and process failures. Investment processes are overseen by independent risk functions which are subject to independent audit and supervised by regulators.
- Real estate risk: Cost of acquisition and disposal, taxation, planning, legal, compliance and other factors can materially impact real estate valuation.
- Liquidity risk: Liquidity is a measure of how easily an investment can be converted to cash without a loss of capital and/or income in the process. The value of assets may be significantly impacted by liquidity risk during adverse market conditions.

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