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Weighting for the Right One: Weighting Scheme Design for Systematic Equity Portfolios†

Wei Dai‡, Namiko Saito‡, Gigi Wang‡

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‡ Dimensional Fund Advisors.

Abstract

We examine eight weighting schemes frequently used in the construction of systematic equity strategies. Through the lens of both returns- and holdings-based analysis, we highlight the importance of having a close link between security weights and market prices. Ignoring prices, as in the cases of equal weighting, rank weighting, z-score weighting, inverse volatility weighting, and fundamental weighting, can result in extreme and uncontrolled deviations relative to the market, as well as excessive turnover and costs. Furthermore, our analysis of three price-based weighting schemes identifies the integrated core approach as the most effective at targeting multiple premiums, ensuring robust risk control, reducing turnover and costs, and accounting for different investor objectives and practical considerations.

1. Introduction

Not all systematic strategies are created equal. Even strategies that target the same set of premiums can differ substantially in how they deviate from market cap weights to pursue higher expected returns. If designed poorly, the strategies may not be able to translate research insights about the premiums into real-world value adds. In contrast, a well-thought-out weighting scheme can provide not only effective exposure to the desired premiums, but also robust risk control and higher cost efficiency.

A key aspect of a well-designed weighting scheme is the link between security weights and market prices. Current market prices reflect the latest news and aggregate expectations of market participants, providing real-time information about expected return differences across securities. By closely tying weights to prices, investors can effectively consider up-to-date information and target higher expected returns. Such a weighting scheme also acts as a robust risk control, allowing investors to directly manage the over- and underweights relative to market cap weights. Without a close tie to market prices, continuous price movements can drive up turnover and the costs of maintaining desired security weights. Price-based weighting schemes help limit those costs by continuously and gradually adjusting security weights as prices change.

In this paper, we examine weighting schemes frequently used in the construction of systematic equity strategies. We start with weighting schemes that break the link between security weights and market prices. We believe our results confirm the perils of ignoring prices when setting security weights. We then compare various price-based weighting schemes to illustrate the additional considerations relevant for weighting scheme design. Viewed through multiple data lenses, the integrated core approach that pursues multiple premiums in a balanced and cost effective manner stands out as an example of a robust yet flexible weighting scheme that can help investors pursue higher expected returns.

2. Weighting Schemes That Ignore Prices

We study five non-price-based weighting schemes: equal weighting, rank weighting, z-score weighting, inverse volatility weighting, and fundamental weighting. Some weighting schemes, such as rank and z-score weighting, are employed to directly emphasize the size, value, and profitability premiums, while others may do so indirectly or focus on other return drivers. While these weighting schemes differ in terms of which premiums they consider and how, they all ignore market prices when setting security weights. We apply those weighting schemes to simulated strategies that invest in the US equity market and are rebalanced semiannually at the end of June and end of December. Security weights are determined as follows.

- **Equal weighting:** All firms are held at the same weight.
- **Rank weighting:** Firms are ranked from 1 to N, with N being the total number of firms, based on independent univariate sorts on their market capitalization (from large to small caps), relative price (from growth to value), and profitability (from low to high profitability). That is, smaller, deeper value, or more profitable firms have higher ranks, while larger, growthier, or less profitable firms have lower ranks. We re-rank the firms according to their average ranks across those three independent sorts, which makes for gradual changes in the weights across firms and avoids abrupt changes.[1] Firms are then weighted in proportion to their final ranks.
- **Z-score weighting:** We first calculate each firm's market capitalization, relative price, and profitability z-scores, defined for each dimension as the corresponding characteristic's raw value minus its cross-sectional average, divided by its cross-sectional standard deviation. The z-scores are then transformed into a value between 0 and 1 using the cumulative distribution function of the standard normal distribution.[2] The transformed z-scores are bigger (closer to 1) for smaller, deeper value, or more profitable firms, and smaller (closer to 0) for larger, growthier, or less profitable firms. Finally, firms are weighted in proportion to the product of their transformed z-scores, which still ranges from 0 to 1.
- **Inverse volatility weighting:** Firms are weighted in proportion to the inverse of their return volatility, where volatility is calculated as the standard deviation of daily returns over the trailing 60 trading days (with a minimum of 20 trading days). That means firms with lower recent volatility are held at larger weights, while more volatile names are assigned smaller weights.
- **Fundamental weighting:** Firms are weighted in proportion to their "economic footprint," measured as the sum of book equity, sales, and cash flow in the latest fiscal year.

[1] After re-ranking, the final ranks between adjacent companies are evenly spaced with an increment of one, except for cases where companies have the same average rank. For example, suppose there are five companies in the universe with average size/value/prof ranks of 2, 2.67, 2.67, 3.67, and 4. After re-ranking, their final ranks will be 1, 2, 2, 4, and 5, respectively.

[2] The cumulative distribution function of the standard normal distribution is written as $\Phi(z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} e^{-t^2/2}\,dt$. We use $1 - \Phi(z)$ for market capitalization and relative price and $\Phi(z)$ for profitability so that the corresponding transformed z-scores increase from 0 to 1 in the direction of higher expected returns, namely, from large to small caps, from high to low relative price, and from low to high profitability.

2.1 Strategy Performance

Exhibit 1 summarizes the performance of simulated strategies under different weighting schemes from July 1974 to December 2019. All simulations outperform the market, with annualized excess returns ranging from 1.7% for fundamental weighting to 6.0% for z-score weighting. The annualized volatility of the fundamental weighted and the inverse volatility weighted simulations is about 16%, or slightly higher than that of the market (15.5%), while the volatility of the other three weighting schemes is around 20%. The range of tracking error against the market is wide: over 10% annualized for equal weighting, rank weighting, and z-score weighting, followed by 7.6% for inverse volatility weighting, with the lowest at 4.5% for fundamental weighting.

Turning to Fama/French five-factor regressions and historical average characteristics, we can gain useful insights into the premium exposures provided by different weighting schemes. All weighting schemes tilt toward small cap and value securities, as evidenced by their positive coefficients on the size and value factors. Consistent with the factor loadings, their weighted average market capitalization and aggregate price-to-book are also lower than those of the market.

The magnitude of these overweights in small caps points to a drawback common to non-price-based weighting schemes: by breaking the link between market prices and security weights, even the smallest names can end up with sizable weights in the strategy. While this issue appears less pronounced in the case of fundamental weighting because large cap companies tend to have bigger fundamentals, it can often lead to extreme outcomes. For example, z-score weighting has a weighted average market capitalization of $281 million, about 1/200th of that of the market ($53.4 billion), and a coefficient of 0.95 on the size factor. Although the weighting scheme is applied to the all cap universe (mega caps to micro caps), these figures are on par with, if not more extreme than, those of a pure small cap strategy.

The profitability tilt looks more mixed across simulations. Interestingly, for rank and z-score weighting schemes, the exposure to the profitability factor is negative and the weighted average profitability is meaningfully lower than that of the market, despite an explicit focus on the profitability premium.

The regression intercept, or alpha, shows a strategy's average excess return, controlling for its exposure to the known return drivers. For fundamental weighting, the lack of a positive alpha is consistent with Lee and Singh (2015). That is, fundamental weighted strategies outperform the market due to their indirect exposure to securities with higher expected returns but do not add value over their tilts to the premiums. The excess returns are positive for the other weighting schemes and reliably so for rank weighting, z-score weighting, and inverse volatility weighting. These results, however, should be interpreted with a heap of salt. As we will show later, the reliable alphas disappear once we exclude micro caps from the eligible universe. This suggests that the shining performance of those strategies on paper is unlikely to survive in the real world once we account for trading costs.

2.2 Holdings Analysis

Strategy Weights by Market Segment

Exhibit 2 shows the breakdown of strategy weights into market capitalization, relative price, and profitability segments as of the end of 2019. Consistent with the factor exposures and aggregate characteristics, Panel A shows significant overweights in small and micro caps across most weighting schemes. For every dollar invested in the z-score weighted strategy, more than 90 cents is in micro caps, which make up the bottom 4% of the market capitalization. For rank weighting the allocation to micro caps is similarly high, above 80%, followed by around 65% for equal weighting and slightly above 50% for inverse volatility weighting. These results are consistent with the observations made in Novy-Marx (2016) and Novy-Marx and Velikov (2022), which show that rank weighting and z-score weighting lead to significant overweight in the smallest names, effectively providing a "backdoor" to equal weighting.

Panel B shows clear value tilts across the board. Value stocks, defined as the bottom half by market capitalization when ranked on price-to-book, make up more than 90% of the rank weighted and z-score weighted simulations, and around 75% of the other three simulations.

In Panel C, we break down the strategy weights by profitability. High profitability stocks are defined as the top half of the market ranked on operating profitability. We observe a meaningful overweight in low profitability firms not only for weighting schemes that do not explicitly consider profitability, but also for rank weighted and z-score weighted simulations, which seemingly place equal emphasis on size, value, and profitability in the calculation of average ranks and z-scores. These results, however, should not be surprising. Because smaller cap and deeper value firms tend to have lower profitability, a naive combination of factor ranks or z-scores does not effectively account for such interactions between the premiums and may lead to offsetting tilts.

Firm-Level Weight Ratios

In addition to the positioning across market segments, we examine how the strategies' over- and underweights are distributed across individual holdings. **Exhibit 3** shows the distribution of firm-level weight ratios relative to the market as of the end of 2019. Hypothetically, if a firm made up 0.15% of the strategy and 0.10% of the market, its weight ratio would be 1.5, and its weight in the strategy would be added to the bar representing weight ratios between one and two. Not surprisingly, weighting schemes that have more overweight in the micro cap segment also tend to have more extreme overweight at the individual company level. For example, the weight ratios are above 100 for almost half of the z-score weighted simulation and for one third of the rank weighted simulation. The right tail is also pronounced for equal weighting and inverse volatility weighting, with around 20% and 10%, respectively, in the weight ratio bucket of above 100. Even fundamental weighting is not immune to the issue of extreme firm-level overweight—while the vast majority of the simulation has moderate weight ratios below five, there is still nonzero weight at the higher end of the spectrum.

The significant overweight in the smallest names in turn leads to significant underweight in the biggest names. This is illustrated in **Exhibit 4** using the FANMAG stocks—Facebook, Amazon, Netflix, Microsoft, Apple, and Google (now trading as Alphabet)—as examples. In many cases, the strategy weights of these stocks are only a tiny fraction of their market cap weights. For example, with its market capitalization of more than $1 trillion as of December 2019, Apple tops the US market and makes up 4.1% of the aggregate market capitalization. Its weight is cut by almost two thirds to 1.6% under fundamental weighting, and down to only a few basis points under equal weighting, rank weighting, and inverse volatility weighting. In the most extreme case, z-score weighting assigns Apple a weight of 0.002 of a basis point, equivalent to the market weight of a nano cap stock with a market capitalization of $6 million.

After examining the cross-section of over- and underweights under different weighting schemes, we turn our attention to how firm-level weight ratios evolve over time. Market prices contain real-time information about company-specific and marketwide events, reflecting the continuously updated aggregate expectations of market participants. This information is valuable not only for assessing expected returns, but also for managing risks, including risks of bankruptcy, delisting, and liquidation. Non-price-based weighting schemes effectively ignore such information when updating security weights, which can compromise their ability to control risk and lead to poor investment decisions.

To illustrate this point, we look at several major bankruptcies in recent decades and study how these companies are treated on their way to bankruptcy under different weighting schemes. **Exhibit 5** shows the strategy-to-market weight ratios of Northwest Airlines, Lehman Brothers, General Motors, and Sears in the five years leading up to their bankruptcies. Not surprisingly, since security prices quickly reflect companies' prospects, the prices and market capitalization of these companies fall as they approach bankruptcy. However, non-price-based weighting schemes largely ignore such information. Thus, the disconnect between strategy weights and market weights leads to sharp increases in the weight ratios, as shown in Exhibit 5.

This issue is particularly notable for fundamental weighting, which increased the level of overweight by the most in all four cases. For example, five years before Chapter 11, Sears had a market capitalization of $6.3 billion, representing 3.4 basis points of the aggregate market capitalization. Based on its "economic footprint," such as book equity, sales, and cash flow, fundamental weighting held Sears at eight times overweight relative to its market weight. After that, Sears' market capitalization gradually decreased over time, and by the time of its bankruptcy filing in September 2018, it only made up one-tenth of one basis point of the market. In contrast, company fundamentals are updated less frequently than market prices, and hence they do not keep up with the sharp decline in market capitalization as a firm heads toward bankruptcy. As a result, Sears ended up with a fundamental weight 70 times larger than its market weight in the last few months before the Chapter 11 filing.

Overall, the holdings analyses in this section show that non-price-based weighting schemes often lead to an unbalanced emphasis on the premiums and extreme over- and underweights across market segments and individual holdings, thus exposing investors to unnecessary idiosyncratic risks and unintended outcomes. Such uncontrolled deviations relative to the market—in particular in the form of extreme overweights in smaller stocks—also make the results less relevant for real-world implementation. We further examine these practical implications in the next section.

2.3 Turnover and Costs

Weighting scheme design plays an important role in determining the turnover and costs of managing a strategy in the real world. Imagine a market cap-weighted portfolio, a special case of a price-based weighting scheme in which security weights in the portfolio are perfectly tied to their market cap weights. In that case, security weights naturally evolve with price changes, so no rebalancing is needed to maintain the desired weights unless the list of securities changes. Weighting schemes that deviate from market weights but still maintain a close link to market prices also benefit from such natural rebalancing. In contrast, when security weights are disconnected from market prices, even small price changes can trigger meaningful turnover across the entire portfolio.

Indeed, **Exhibit 6** shows relatively high turnover for different non-price-based weighting schemes from July 1974 to December 2019. In addition to overall turnover, we also calculate turnover by size group, defined as the absolute weight change within a size group divided by the weight of that size group. At the overall portfolio level, fundamental weighting has the lowest one-way turnover of 20% per year due to the positive correlation between market capitalization and company fundamentals. The average annual one-way turnover for other weighting schemes is meaningfully higher, ranging from 33% for equal weighting to 54% for z-score weighting. Across size groups, turnover tends to increase with decreasing market capitalization. Within micro caps, turnover ranges from 34% for fundamental weighting to above 50% for z-score weighting and inverse volatility weighting. These figures are particularly informative about potential implementation costs because smaller stocks, which are significantly overweight under non-price-based weighting schemes, tend to be more costly to trade.

To put things into perspective, consider a micro cap stock with a market capitalization of $150 million and a market weight of 0.05 of a basis point. An overweight of 100 times, which is not uncommon as we have seen earlier, means this stock will account for 5 basis points of the portfolio. A $1 billion portfolio will seek to buy $500,000 worth of that stock on the rebalancing date. For a micro cap stock, this purchase could be the majority of its normal average daily trading volume, or even multiple times that amount. Such demand for excessive liquidity from the market can lead to price impacts and unnecessarily high trading costs. For example, trade cost analysis conducted by one of the largest US market makers shows that a higher participation rate, measured by the value of an executed trade as a percentage of the traded stock’s average daily volume, is associated with higher implementation costs. For global equity trades in 2020, average implementation costs are 65 basis points for trades with participation rates above 5%, more than double the implementation costs of 31 basis points for trades with participation rates below 5%.[3] These implementation costs are averaged across trading orders of all sizes and are likely to be meaningfully larger for micro caps. The higher costs per unit of turnover, combined with a high turnover level, casts strong doubt on the practical relevance of non-price-based weighting schemes.

Alternatively, one can limit the participation rate to keep trading costs low, but that means the desired turnover may take longer to execute. That is, there is a natural tension between price, quantity, and time when it comes to real-world trading. **Exhibit 7** illustrates this through a portfolio liquidation analysis as of December 2019, assuming $1 billion in assets and a maximum participation rate of 5%. Except for fundamental weighting, only 34%–68% of the simulated strategies can be liquidated within one day, and 12%–40% of the strategies remain unsold after 10 trading days. The time needed for liquidation is substantially longer for weighting schemes with more allocations to small and micro caps. For example, after 10 days of trading, 28% of the rank weighted simulation and 40% of the z-score weighted simulation are yet to be sold. Further, in periods of market stress and heightened volatility, non-price-based weighting schemes may face even more challenges in getting the trades done at a reasonable price within an acceptable time period.

2.4 Excluding Micro Caps

If many of the issues associated with ignoring prices have to do with smaller stocks, can we make non-price-based weighting schemes work by simply excluding micro caps? In this section, we repeat the analysis in the ex-micro universe.

While excluding micro caps has little impact on long-term market returns, it meaningfully reduces the historical performance of all weighting schemes considered thus far over the same sample period from July 1974 to December 2019. As shown in Panel A of **Exhibit 8**, the ex-micro simulations deliver noticeably lower annualized premiums vs. the ex-micro market compared to their all cap counterparts. Not surprisingly, the reduction in returns is greater for weighting schemes with more overweight in micro caps and better performance previously. For example, the annualized premium vs. the market is cut by almost half for rank weighting and z-score weighting, from 5.0% to 3.0% and from 6.0% to 3.5%, respectively. Similarly, Panel B shows that the intercept of the Fama/French five-factor regressions drops significantly across the board. In the ex-micro universe, none of the weighting schemes produce a reliably positive alpha—in fact, the intercepts are all close to zero and mostly negative. In summary, these weighting schemes derive much of their outperformance from disproportional overweight to micro cap names.

Exhibit 9 presents the historical performance of ex-micro simulations in greater detail along with their premium exposures. While excluding micro caps mitigates some of the extreme cases—for example, no more firm-level overweight of above 100 times—the issues stemming from the disconnect between security weights and market prices do not completely go away. As indicated by

[3] Source: Virtu ITG LLC. Participation rate describes the percentage an executed trade makes up of the traded stock's average daily volume.

the coefficients on the size factor and the weighted average market capitalizations, most weighting schemes still end up with significant tilts to smaller names. We also continue to observe extreme underweight in the largest names. For example, as of December 2019, Apple makes up 4.3% of the US market (excluding micro caps) but is only held at 1.8% in the fundamental weighted simulation, and 3–12 basis points under rank weighting, equal weighting, and inverse volatility weighting. Under z-score weighting, Apple's weight is 0.0003 of a basis point in the ex-micro simulation, even lower than that in the all cap simulation. That means a $1 billion portfolio would only allocate $30 to the largest stock in the market.

Small and micro caps are a part of the market and provide diversification benefits to large cap allocations. Rather than simply excluding these stocks, a more effective approach is to design a weighting scheme that allows for risk-controlled, cost-effective capture of their returns. To achieve that, we now turn to price-based weighting schemes.

3. Price-Based Weighting Schemes

Increasingly, we see the incorporation of market prices into the weighting scheme design of factor-based indices and strategies, perhaps due to the many drawbacks of non-price-based weighting schemes. While considering prices is a good starting point, it requires additional expertise to design a robust yet flexible price-based weighting scheme. We illustrate the relevant considerations through a comparison of three price-based weighting schemes in this section. All three weighting schemes target the size, value, and profitability premiums in the US market. The simulations are again rebalanced semiannually at the end of June and end of December, with security weights determined as follows.

- **Rank x mcap (rank-times-mcap):** Firms are weighted in proportion to their final ranks (defined the same as above for rank weighting) multiplied by their market capitalization.
- **Z-score x mcap (z-score-times-mcap):** Firms are weighted in proportion to the product of their transformed z-scores (defined the same as above for z-score weighting) multiplied by their market capitalization.
- **Integrated core:** Firms are independently sorted on their market capitalization, relative price, and profitability. The intersections of this three-way sort form groups of firms with similar characteristics. For example, mega cap firms with higher relative price and higher profitability form one group, while mega cap firms with higher relative price but lower profitability form another group. Within each group, firms are held in proportion to their market capitalizations. Each group is weighted in proportion to its total market capitalization times a multiplier, where the multiplier effectively controls the group's over- or underweight relative to the market and gradually increases as we move from groups with lower expected returns to those with higher expected returns. The multipliers used in this study are designed

to achieve a moderate and balanced emphasis on the size, value, and profitability premiums while accounting for the interactions among them.

3.1 Strategy Performance

Exhibit 10 shows the historical performance, factor regressions, and average characteristics of the different weighting schemes from July 1974 to December 2019. Rank-times-mcap and integrated core both deliver an annualized compound return of 13.5%, outperforming the market return of 11.8%. The tracking error relative to the market is slightly lower for integrated core compared to rank-times-mcap (2.9% vs. 3.0% annualized). In comparison, z-score-times-mcap delivers a higher annualized premium of 3.3%, but that outperformance also comes with a larger tracking error of 7.4%.

While rank-times-mcap and integrated core have similar long-term performance, the exposures they provide to the targeted premiums are not identical. The coefficients on the size, value, and profitability factors are 0.11, 0.24, and 0.09 for rank-times-mcap and 0.19, 0.15, and 0.13 for integrated core. That means rank-times-mcap has less exposure to the size and profitability premiums but more exposure to the value premium compared to integrated core. On the other hand, z-score-times-mcap achieves its higher returns through a much bigger emphasis on the size and value premiums, as indicated by a size factor coefficient of 0.61 and a value factor coefficient of 0.35. The historical average characteristics tell a similar story.

It's also interesting to compare rank-times-mcap and z-score-times-mcap in Exhibit 10 with their non-price-based counterparts in Exhibits 1 and 9. As expected, the incorporation of market capitalization in weighting scheme design helps reduce the overweight in small caps and better control the deviations from the market.

3.2 Holdings Analysis

Strategy Weights by Market Segment

Exhibit 11 shows the positioning under each weighting scheme across different size, relative price, and profitability segments as of the end of 2019. Consistent with the observations above, the allocation to large vs. small caps confirms that z-score-times-mcap has the strongest size tilt among the three simulations: half of the strategy is allocated to small caps, or over 6 times the market's weight of 7.8% in small caps. In comparison, rank-times-mcap and integrated core have more moderate small cap allocations of 14.7% and 18.2%, respectively.

Within each size group, we also see interesting differences among weighting schemes in their allocations across the relative price and profitability segments. Integrated core has a relatively balanced emphasis on the value and profitability premiums. For example, within the large cap group, the value-high profitability segment has the most overweight (1.36 times market weight) and the growth-low profitability segment has the most underweight (0.45 times market weight), while the growth-high profitability and value-low profitability segments have similar strategy-to-market weight ratios of 0.84 and 0.93, respectively.

For rank-times-mcap, while the weight ratios also gradually increase in the direction of higher expected returns, the increase is more prominent along the relative price dimension than along the profitability dimension. For example, within large caps, the value-low profitability segment has a weight ratio of 1.12, meaningfully higher than the weight ratio of 0.74 for the growth-high profitability segment. This indicates a stronger focus on value than on profitability, even though it equally weights the ranks based on size, value, and profitability. These observations are consistent with the factor regressions shown earlier.

Lastly, z-score-times-mcap leads to the least balanced tilt towards the premiums, with the value tilt clearly dominating the profitability tilt. The segments within value have much higher strategy-to-market weight ratios than those within growth, but we do not observe the same emphasis on high profitability segments relative to their low profitability counterparts. For example, within large growth, the high profitability segment actually has a lower strategy-to-market weight ratio than the low profitability segment (0.15 vs. 0.23); within large value, the high and low profitability segments have almost identical weight ratios (0.96 vs. 0.95).

Firm-Level Weight Ratios

Exhibit 12 presents the distribution of weight ratios across individual holdings in each simulation. For integrated core and rank-times-mcap, many of the high weight ratio groups, which were well populated under non-price-based weighting schemes, are now empty. All holdings have weight ratios below three in the integrated core simulation and below five in the rank-times-mcap simulation. In comparison, z-score-times-mcap has a much wider distribution and more allocation to firms with greater overweight: almost 20% of the strategy has weight ratios above 10 and the maximum is 50.

These results suggest that tying security weights to market prices helps to avoid extreme and uncontrolled deviations from the market, but to a varying degree. Among the price-based weighting schemes, integrated core leads to a more balanced emphasis on the premiums and more measured over- and underweights across holdings, while rank-times-mcap is a close second on these metrics.

3.3 Turnover and Costs

As discussed earlier, maintaining a close tie between security weights and market prices helps to limit excessive turnover and costs. While this is an advantage for all price-based weighting schemes, integrated core takes the benefits further. Recall that, in the rank-times-mcap and z-score-times-mcap simulations, over- and underweights are directly determined at the firm level, by each firm's average rank or z-score. In contrast, the integrated core weighting scheme first groups firms on their size, relative price, and profitability characteristics and then determines the multipliers to control the over- and underweights at the group level. Because firms are weighted in proportion to their market capitalization within each group, the integrated core weighting scheme can take advantage of the natural rebalancing mechanism that comes with market cap weighting. The grouping approach also implies that small changes in characteristics will not lead to different groupings and trigger additional trading, so this weighting scheme can effectively focus on turnover that meaningfully increases expected returns after costs. Further, because the multipliers vary across groups in a gradual and controlled manner, the changes in a company's desired over- or underweight and the required turnover are likely moderate as a company migrates from one group to another due to changes in share prices and fundamentals.

These benefits are reflected in the turnover summary shown in **Exhibit 13**. The average annual one-way turnover is 24% for rank-times-mcap and 31% for z-score-times-mcap, more than 20 percentage points lower than the turnover figures of their non-price-based counterparts shown in Exhibit 6. The integrated core weighting scheme further reduces the turnover to 22% per year. Integrated core also has the lowest turnover consistently within each size group. For example, within micro caps, the average annual turnover is 21% for integrated core, compared to 27% for rank-times-mcap and 32% for z-score-times-mcap. We believe these results confirm that incorporating prices into weighting scheme design, especially through the integrated core approach, offers a more efficient pursuit of the premiums.

3.4 Achieving the Desired Allocations

While we have focused on one strategy design (all cap marketwide) under each weighting scheme so far, it is worth considering the flexibility a weighting scheme offers to achieve the desired exposures to the premiums in different strategies. From that perspective, the integrated core approach has distinct advantages as it allows us to better account for interactions among premiums and more directly manage the exposures to different premiums.

We illustrate that in **Exhibit 14** through a hypothetical example of two companies: Company A, a small cap company with a high relative price and low profitability, and Company B, a large cap company with a low relative price and high profitability. Valuation theory and empirical research show that stocks like Company A have lower expected returns than the overall small cap market. Using the integrated core approach, we can systematically account for such interactions among premiums and increase expected returns by underweighting or excluding Company A, along with other stocks in the small growth-low profitability group. For Company B, its value and high profitability characteristics indicate a higher expected return potential than other large cap stocks with higher relative prices and/or lower profitability, so we might want to overweight it within large caps. To achieve that, we can assign a larger multiplier to the large cap value-high profitability group, which Company B belongs to, than to other large cap groups. The multipliers directly control the amount of over- and underweight and can be customized to achieve different allocations across the size, value, and profitability segments.

Weighting schemes like rank-times-mcap do not offer the same direct control. Continuing with the example above, out of 3,000 companies, Company A is ranked 2,750th on market capitalization, 800th on relative price, and 800th on profitability. Company B has a market capitalization rank of

50, a relative price rank of 2,300, and a profitability rank of 2,000. Despite having very different underlying characteristics, Company A and Company B end up with the same average rank. Since companies are weighted in proportion to their average ranks multiplied by market capitalization, Company A and Company B will have the same amount of over- or underweight measured by the ratio of their portfolio weights to market weights. And for companies with different ranks, the fact that ranks are "equally spaced" also makes it more difficult to customize the variation of over- and underweights across companies or groups of companies.

That said, there is still some room for customization as one can assign different weights to the size, relative price, and profitability ranks instead of taking simple averages. The mapping between the weights on the three premiums and the resulting exposures, however, may not be straightforward and may be largely at the mercy of the time-varying interactions among the premiums. Indeed, as we have seen earlier, equal weighting of the ranks does not necessarily lead to a balanced emphasis on the premiums. While one can seek to optimize the security weights to achieve certain factor exposures, the optimization process is often opaque, and the results can be very sensitive to estimation noise and assumptions. There is no guarantee that the optimized weights based on the historical or modeled interactions among the premiums should result in consistent exposure in the future. In contrast, the integrated core approach achieves the desired exposures in a much more transparent and robust way.

The integrated core weighting scheme also makes it easier to incorporate other considerations, like turnover and costs. For example, the expected costs of additional turnover are higher for small caps than for large caps, so it makes sense to design the weighting scheme in such a way that the over- and underweights change more gradually within small caps than large caps. Using the integrated core approach, we can assign multipliers with more moderate gradients across small cap groups, thus reducing the expected turnover and costs associated with maintaining the desired weights as small cap names migrate across groups. This is again a more transparent and controlled way to address practical considerations in weighting scheme design than building various security and turnover constraints into an opaque optimization process.

Whether it's a choice between lighter or heavier tilts toward all three premiums, more emphasis on one premium over another, or a different emphasis on large caps vs. small caps due to real-world considerations, we believe the integrated core approach offers greater flexibility to achieve the desired outcomes.

4. Choosing the Right Weighting Scheme

Our study highlights the important principles when it comes to choosing the right weighting scheme. Top of the list is a strong tie between market prices and security weights. Ignoring prices, as in the cases of rank weighting and z-score weighting, can result in extreme and uncontrolled deviations relative to the market, as well as excessive turnover and costs. While the incorporation of market prices in weighting scheme design is a must, designing a robust yet flexible price-based weighting scheme requires additional expertise. Among the various price-based weighting schemes, we find that the integrated core approach is more effective at integrating multiple premiums, ensuring robust risk control, reducing turnover and costs, and accounting for different investor objectives and practical considerations.

More broadly, our study serves as a reminder that investors need to look beyond performance, especially simulated performance, and look under the hood of investment strategies. Weighting scheme design is among the many aspects to consider when assessing systematic strategies.

Exhibits

EXHIBIT 1

Summary of Historical Performance and Exposures to Premiums, Non-Price-Based Weighting Schemes, July 1974–December 2019

	Market	Equal Weighting	Rank Weighting	Z-score Weighting	Inverse Volatility Weighting	Fundamental Weighting
July 1974–December 2019						
Annualized Compound Return (%)	11.8	13.8	16.8	17.9	15.3	13.6
Annualized Standard Deviation (%)	15.5	19.9	19.8	19.8	16.2	16.0
Annualized Premium vs. Market (%)		2.0	5.0	6.0	3.4	1.7
Annualized Tracking Error vs. Market (%)		10.7	12.0	12.9	7.6	4.5
Fama/French Five-Factor Regressions						
Intercept (Not Annualized)		0.10	0.26	0.34	0.14	–0.05
t-Stat of Intercept		1.43	2.83	3.28	3.26	–1.53
Market		0.95	0.91	0.87	0.87	1.05
Size		0.86	0.92	0.95	0.67	0.11
Value		0.11	0.30	0.36	0.17	0.33
Profitability		–0.18	–0.09	–0.07	0.07	0.14
Investment		–0.05	–0.08	–0.11	0.02	0.04
R2		0.93	0.88	0.85	0.96	0.97
Historical Average Characteristics						
Weighted Average Market Capitalization ($million USD)	53,352	2,251	1,091	281	3,460	40,120
Aggregate Price-to-Book	2.21	1.34	1.02	0.89	1.40	1.45
Weighted Average Profitability	0.33	0.13	0.19	0.20	0.20	0.31

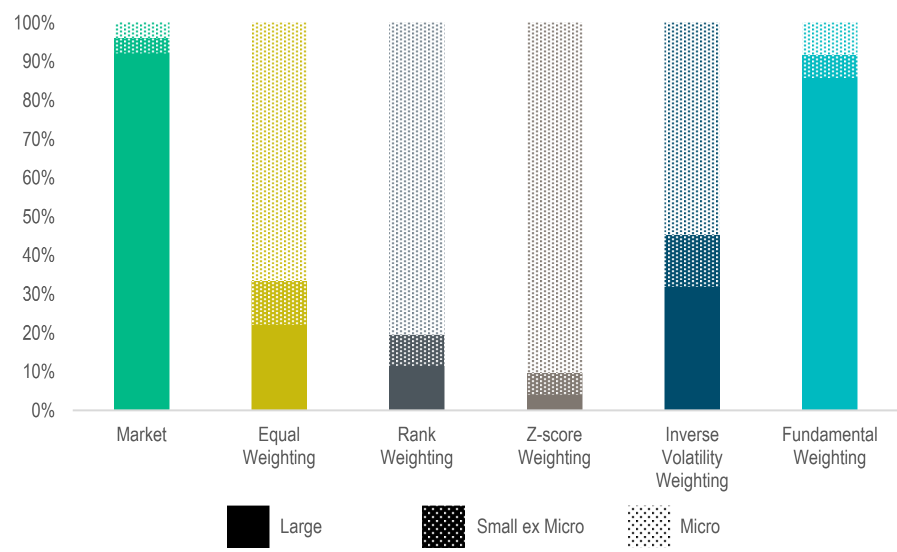
Past performance, including hypothetical performance, is no guarantee of future results.

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. Fama/French factors data are from Kenneth French's data library (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html).

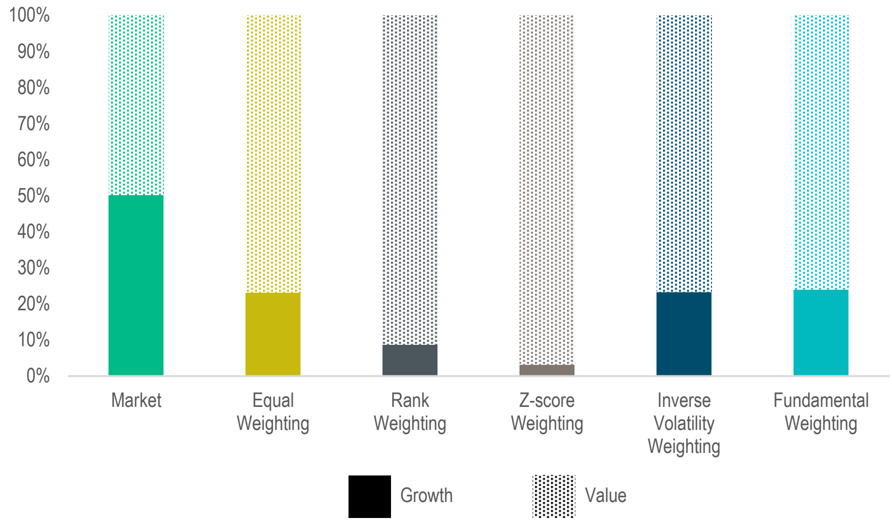
EXHIBIT 2

Strategy Weights by Market Segment, Non-Price-Based Weighting Schemes, as of December 2019

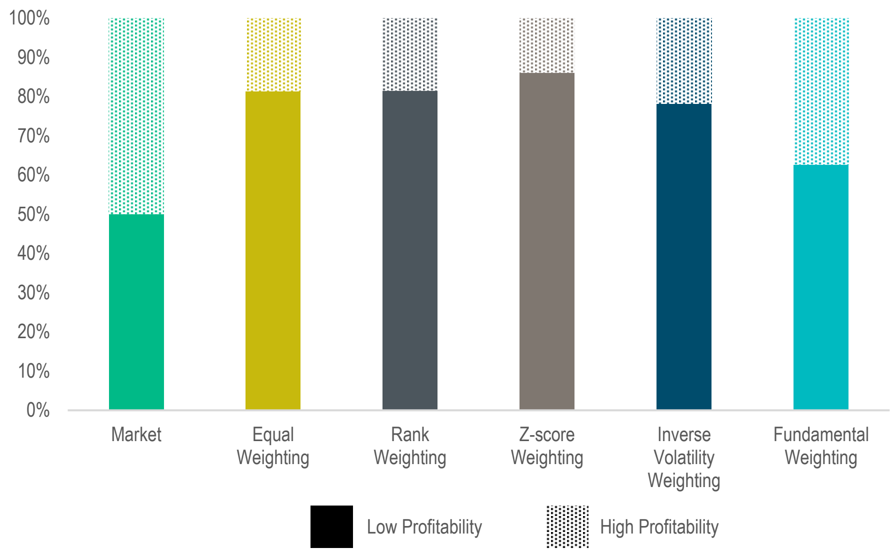
PANEL A. BY MARKET CAPITALIZATION



PANEL B. BY RELATIVE PRICE



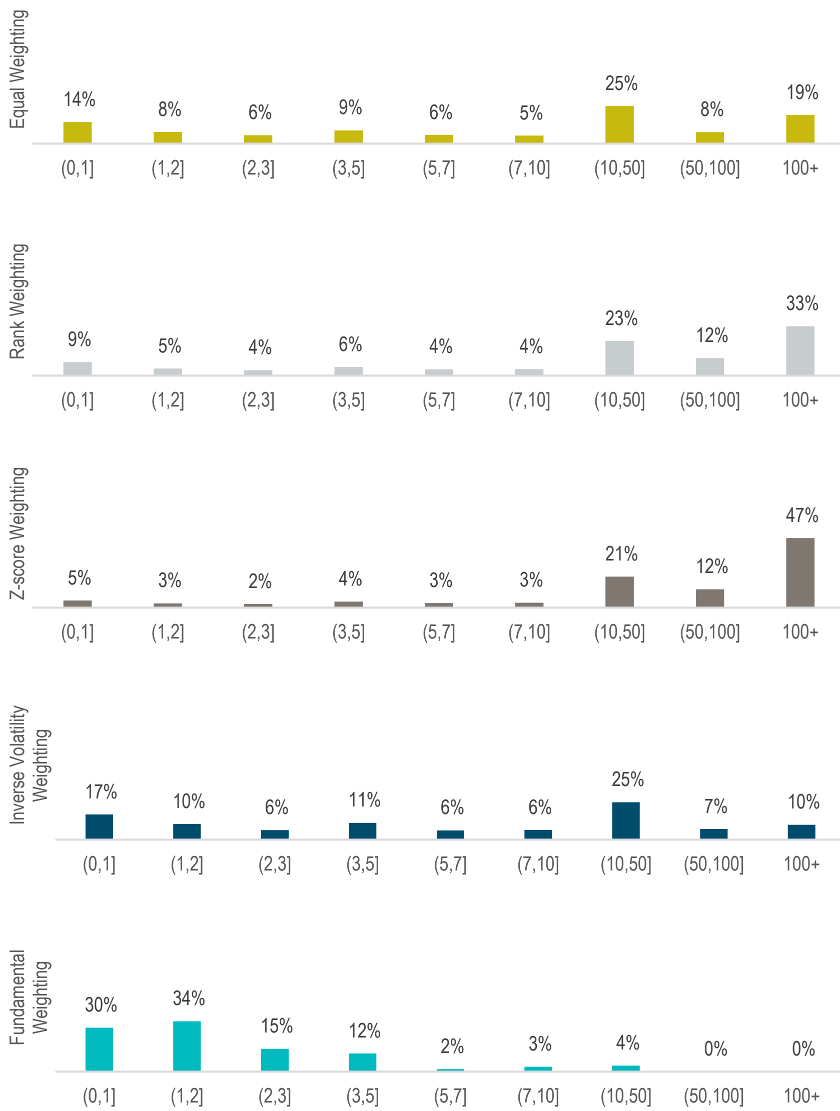
PANEL C. BY PROFITABILITY



Source: Dimensional using CRSP and Compustat data. The exhibit shows the distribution of each simulated strategy's weights across the market capitalization, value, and profitability segments. Large cap is defined as approximately the top 92% of the market capitalization. Small cap and micro cap are defined as approximately the bottom 8% and 4% of the market capitalization, respectively. Value is defined as the 50% of the market capitalization with the lowest price-to-book ratios, and growth is the top 50%. High profitability is defined as the 50% of the market capitalization with the highest profitability, and low profitability is the lowest 50%. Firms without relative price and profitability data are excluded from this analysis. See Appendix for additional information on the simulated strategies.

EXHIBIT 3

Distribution of Firm-Level Weight Ratios Relative to Market, Non-Price-Based Weighting Schemes, as of December 2019



Source: Dimensional, using the CRSP and Compustat data. For each firm held in each simulated strategy, its firm-level weight ratio is computed as its weight in the strategy relative to that in the market. The exhibit shows the distributions of the simulated strategies' firm-level weight ratios, with the bars representing the total strategy weights of firms that fall within each weight ratio range. Firms that are not held by the simulated strategies have a weight ratio of zero and are excluded from the exhibit. See Appendix for additional information on simulated strategies.

EXHIBIT 4

Market and Strategy Weights of FANMAG Stocks, Non-Price-Based Weighting Schemes, as of December 2019

Company Name	Market Weight (basis point)	Strategy Weight (basis point)				
		Equal Weighting	Rank Weighting	Z-score Weighting	Inverse Volatility Weighting	Fundamental Weighting
Facebook	158	3	1	0.01	4	66
Apple	412	3	1	0.002	5	162
Netflix	45	3	0.3	0.005	3	9
Microsoft	384	3	1	0.001	7	85
Amazon	295	3	1	0.001	6	118
Google (Alphabet)	275	3	1	0.01	0.01	141

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies.

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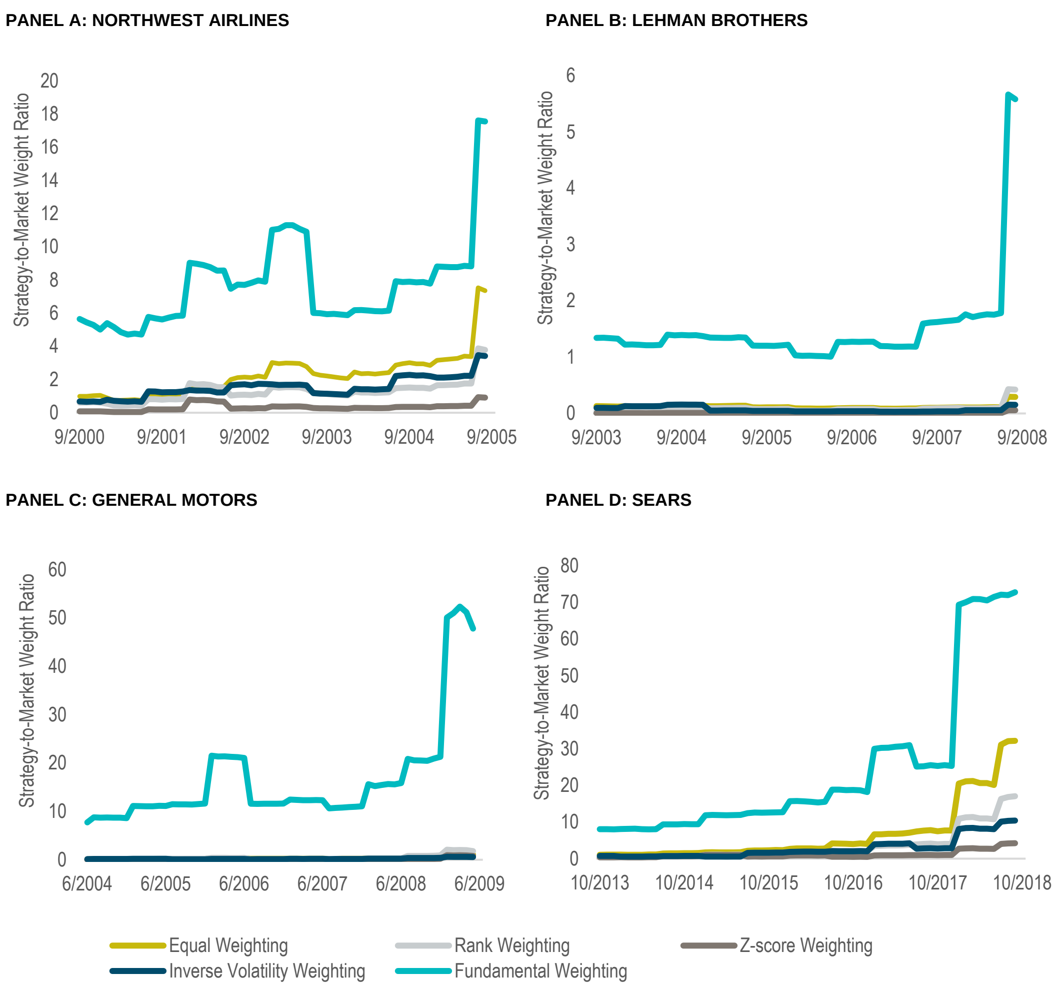
EXHIBIT 5

Weight Ratios Relative to Market in Five Years Leading Up to Bankruptcy



Source: Dimensional, using the CRSP and Compustat data. For each firm shown, its weight ratios are computed as its weight in each simulated strategy relative to that in the market. See Appendix for additional information on simulated strategies. The bankruptcy events are on September 14, 2005, September 15, 2008, June 1, 2009, and October 15, 2018, for Northwest Airlines, Lehman Brothers, General Motors, and Sears, respectively.

EXHIBIT 6

Average Annual One-Way Turnover by Strategy Weight, Non-Price-Based Weighting Schemes, July 1974–December 2019

		Market	Equal Weighting	Rank Weighting	Z-score Weighting	Inverse Volatility Weighting	Fundamental Weighting
Average One-Way Turnover by Strategy Weight	All	6%	32%	48%	54%	43%	20%
	Within Large Caps	6%	24%	44%	53%	33%	18%
	Within Small ex Micro Caps	9%	29%	49%	55%	39%	27%
	Within Micro Caps	11%	36%	48%	54%	50%	34%

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. For each strategy simulation in each month, the overall turnover is calculated as the sum of the absolute change in the position across the holdings, divided by the sum of the ending positions. The monthly turnover within large caps is calculated similarly but within firms that are categorized as large cap. The monthly turnover within small ex micro caps and that within micro caps are also calculated similarly. The exhibit shows the time-series average of the annualized monthly one-way turnover.

EXHIBIT 7

Portfolio Liquidation Analysis, Non-Price-Based Weighting Schemes, December 2019

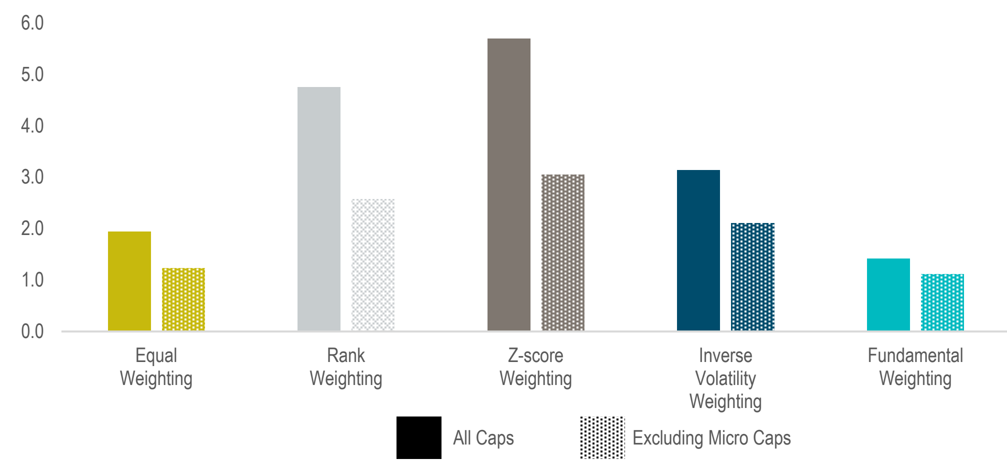
Percent of Portfolio Value That Can Be Liquidated in N Days (assuming $1 billion in assets and maximum 5% participation rate)					
	Equal Weighting	Rank Weighting	Z-score Weighting	Inverse Volatility Weighting	Fundamental Weighting
1 Day	62.70%	46.90%	34.20%	68.40%	98.80%
3 Days	73.60%	59.00%	46.20%	78.70%	99.80%
5 Days	78.20%	64.40%	51.80%	82.90%	99.90%
10 Days	84.20%	71.60%	59.60%	88.00%	99.90%
20 Days	89.60%	78.80%	67.80%	92.20%	100.00%

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. The liquidation analysis assumes $1 billion invested in each simulated strategy as of the end of December 2019. Assuming a maximum participation rate of 5%, the maximum daily number of shares that can be liquidated for each holding is 5% of its total number of shares traded in December 2019 divided by 21 (the number of trading days in December 2019).

EXHIBIT 8

Impact of Excluding Micro Caps on Performance, Non-Price-Based Weighting Schemes, July 1974–December 2019

PANEL A. ANNUALIZED PREMIUM VS. MARKET (%)



PANEL B. FAMA/FRENCH FIVE-FACTOR REGRESSION INTERCEPT (%, MONTHLY)

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. The five factors used in the regressions in Panel B are market (MKT-RF), size (SMB), value (HML), profitability (RMW), and investment (CMA).

EXHIBIT 9

Summary of Historical Performance and Exposures to Premiums, Non-Price-Based Weighting Schemes Excluding Micro Caps, July 1974–December 2019

	Market	Equal Weighting	Rank Weighting	Z-score Weighting	Inverse Volatility Weighting	Fundamental Weighting
July 1974–December 2019						
Annualized Compound Return (%)	11.8	13.2	14.7	15.3	14.1	13.2
Annualized Standard Deviation (%)	15.4	17.9	17.8	17.8	15.6	15.7
Annualized Premium vs. Market (%)		1.4	3.0	3.5	2.3	1.4
Annualized Tracking Error vs. Market (%)		5.9	7.1	8.0	5.1	4.3
Fama/French Five-Factor Regressions						
Intercept (Not Annualized)		–0.01	–0.04	–0.04	0.00	–0.07
t-Stat of Intercept		–0.18	–1.03	–0.84	0.05	–2.03
Market		1.04	1.05	1.04	0.97	1.05
Size		0.47	0.57	0.59	0.36	0.02
Value		0.06	0.28	0.37	0.15	0.30
Profitability		0.01	0.22	0.26	0.20	0.15
Investment		-0.02	-0.02	-0.02	0.06	0.05
R2		0.98	0.97	0.96	0.97	0.97
Historical Average Characteristics						
Weighted Average Market Capitalization ($million USD)	55,536	6,309	3,332	1,690	7,622	43,063
Aggregate Price-to-Book	2.27	1.91	1.63	1.50	1.84	1.54
Weighted Average Profitability	0.34	0.28	0.32	0.30	0.30	0.31

Past performance, including hypothetical performance, is no guarantee of future results.

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. Fama/French factors data are from Kenneth French's data library. (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html).

EXHIBIT 10

Summary of Historical Performance and Exposures to Premiums, Price-Based Weighting Schemes, July 1974–December 2019

	Market	Rank x Mcap	Z-score x Mcap	Integrated Core
July 1974–December 2019				
Annualized Compound Return (%)	11.8	13.5	15.2	13.5
Annualized Standard Deviation (%)	15.5	15.4	17.7	15.7
Annualized Premium vs. Market (%)		1.7	3.3	1.6
Annualized Tracking Error vs. Market (%)		3.0	7.4	2.9
Fama/French Five-Factor Regressions				
Intercept (Not Annualized)		0.01	0.01	–0.01
t-Stat of Intercept		0.64	0.32	–0.50
Market		1.00	1.02	1.01
Size		0.11	0.61	0.19
Value		0.24	0.35	0.15
Profitability		0.09	0.12	0.13
Investment		–0.02	–0.02	0.03
R2		0.99	0.98	0.99
Historical Average Characteristics				
Weighted Average Market Capitalization ($million USD)	53,352	42,548	4,528	33,742
Aggregate Price-to-Book	2.21	1.68	1.31	1.86
Weighted Average Profitability	0.33	0.35	0.27	0.35

Past performance, including hypothetical performance, is no guarantee of future results.

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. Fama/French factors data are from Kenneth French's data library. (http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html).

EXHIBIT 11

Strategy Weights by Market Segment, Price-Based Weighting Schemes, as of December 2019

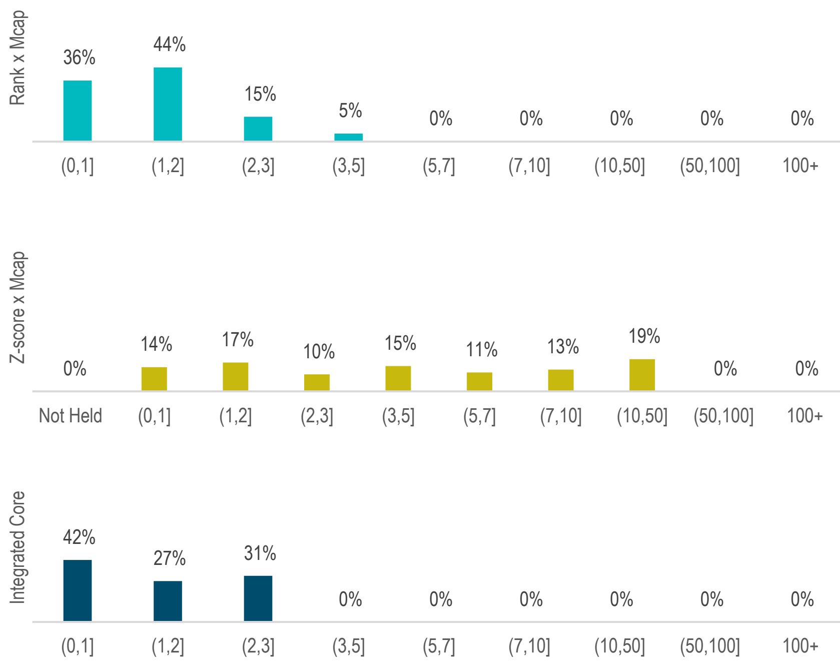
Strategy-to-Market Ratio / Rank x Mcap / Z-score x Mcap / Integrated Core / Market Weight

Segment	Strategy-to-Market Ratio: Rank x Mcap	Strategy-to-Market Ratio: Z-score x Mcap	Strategy-to-Market Ratio: Integrated Core	Rank x Mcap	Z-score x Mcap	Integrated Core	Market Weight
Large Caps	0.93	0.54	0.89	85.3%	50.0%	81.8%	92.2%
Small Caps	1.89	6.43	2.35	14.7%	50.0%	18.2%	7.8%
Large Cap Growth – Low Prof	0.39	0.23	0.45	3.8%	2.2%	4.4%	9.7%
Large Cap Growth – High Prof	0.74	0.15	0.84	28.4%	5.9%	32.2%	38.5%
Small Cap Growth – Low Prof	0.43	1.24	0.95	0.6%	1.8%	1.3%	1.4%
Small Cap Growth – High Prof	1.86	2.25	2.40	1.0%	1.3%	1.4%	0.6%
Large Cap Value – Low Prof	1.12	0.95	0.93	38.1%	32.3%	31.7%	34.1%
Large Cap Value – High Prof	1.52	0.96	1.36	15.0%	9.5%	13.5%	9.9%
Small Cap Value – Low Prof	2.13	8.05	2.64	10.4%	39.1%	12.8%	4.9%
Small Cap Value – High Prof	2.86	8.45	2.91	2.7%	7.9%	2.7%	0.9%

Source: Dimensional, using the CRSP and Compustat data. We show the distribution of each simulated strategy's weights across the market capitalization, value, and profitability segments. Large cap is defined as approximately the top 92% of the market capitalization, and small cap is the bottom 8%. Value is defined as the 50% of the market capitalization with the lowest price-to-book ratios, and growth is the top 50%. High profitability is defined as the 50% of the market capitalization with the highest profitability and low profitability as the lowest 50%. Firms without relative price and profitability data are excluded from this analysis. See Appendix for additional information on the simulated strategies.

EXHIBIT 12

Distribution of Firm-Level Weight Ratios Relative to Market, Price-Based Weighting Schemes, as of December 2019



Source: Dimensional, using the CRSP and Compustat data. For each firm held in each simulated strategy, its firm-level weight ratio is computed as its weight in the strategy relative to that in the market. The exhibit shows the distributions of the simulated strategies' firm-level weight ratios, with the bars representing the total strategy weights of firms that fall within each weight ratio range. Firms that are not held by the simulated strategies have a weight ratio of zero and are excluded from the exhibit. See Appendix for additional information on simulated strategies.

EXHIBIT 13

Average Annual One-Way Turnover by Strategy Weight, Price-Based Weighting Schemes, July 1974–December 2019

		Market	Rank x Mcap	Z-score x Mcap	Integrated Core
Average One-Way Turnover by Strategy Weight	All	6%	24%	31%	22%
	Within Large Caps	6%	23%	32%	22%
	Within Small ex Micro Caps	9%	28%	31%	20%
	Within Micro Caps	11%	27%	32%	21%

Source: Dimensional, using the CRSP and Compustat data. See Appendix for additional information on simulated strategies. For each strategy simulation in each month, the overall turnover is calculated as the sum of the absolute change in the position across the holdings, divided by the sum of the ending positions. The monthly turnover within large caps is calculated similarly but within firms that are categorized as large cap. The monthly turnover within small ex micro caps and that within micro caps are also calculated similarly. The exhibit shows the time-series average of the annualized monthly one-way turnover.

EXHIBIT 14

Illustrative Example of Integrated Core vs. Rank-Times-Mcap Weighting Schemes

	Integrated Core		Rank x Mcap			
	Size/Value/ Profitability Grouping	Weighting	Market Capitalization Rank	Relative Price Rank	Profitability Rank	Average Rank
			(Smallest firm has highest rank)	(Firm with lowest P/B has highest rank)	(Firm with highest profitability has highest rank)	
Company A	Small Cap Growth Low Profitability	Zero Weight (Exclusion)	2750 / 3000	800 / 3000	800 / 3000	1450 / 3000
Company B	Large Cap Value High Profitability	Overweight within Large	50 / 3000	2300 / 3000	2000 / 3000	1450 / 3000

For illustration purposes only. See Appendix for additional information on simulated strategies.

Appendix

Source: Dimensional, using the CRSP and Compustat data. The eligible universe includes all US firms excluding REITs, tracking stocks, and investment companies. Unless otherwise specified, we use the following definitions and methodologies.

Simulations are rebalanced semiannually. For simulations that exclude micro caps, micro cap is defined as approximately the bottom 4% of the market capitalization. Profitability is a company's operating income before depreciation and amortization minus interest expense scaled by book equity. Descriptions of the simulations under different weighting schemes can be found at the beginning of Section 2 and Section 3.

References

Clark, Stephen A., and L. Jacobo Rodríguez. 2010. "The Performance of Small Cap Growth Stocks." *Dimensional Fund Advisors' Quarterly Institutional Review* 6, no. 1: 2–6.

Fama, Eugene F., and Kenneth R. French. 1993. "Common Risk Factors in the Returns on Stocks and Bonds." *Journal of Financial Economics* 33, no. 1: 3–56.

Fama, Eugene F., and Kenneth R. French. 2015. "A Five-Factor Asset Pricing Model." *Journal of Financial Economics* 116, no. 1: 1–22.

Lee, Marlena, and Bhanu Singh. 2015. "Smart Beta." Dimensional Fund Advisors (white paper).

Liu, Jerry, and Ryan Wiley. 2021. "Global Trading Price Advantages of Flexible Equity Portfolios." Dimensional Fund Advisors (white paper).

Novy-Marx, Robert. 2016. "Testing Strategies Based on Multiple Signals" (working paper).

Novy-Marx, Robert, and Mihail Velikov. 2022. "Betting Against Betting Against Beta." *Journal of Financial Economics* 143, no. 1: 80-106.

Rizova, Savina. 2012. "The Performance of International Small Cap Growth Stocks." *Dimensional Fund Advisors' Quarterly Institutional Review* 6, no. 2: 2–7.

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