CONTRIBUTORS

Bill Hao
Director
Global Research & Design
wenli.hao@spglobal.com

Aye M. Soe, CFA
Managing Director
Global Research & Design
aye.soe@spglobal.com

Kelly Tang, CFA
Director
Global Research & Design
kelly.tang@spglobal.com

Carbon Risk Integration in Factor Portfolios

INTRODUCTION

In the past, discussions on carbon risk would typically involve scientific arguments regarding climate change and whether existing evidence supported market participant action for carbon-awareness investing. In recent years, climate change policy and knowledge have progressed to the point where many large institutions across the globe have already begun to incorporate varying degrees of carbon risk integration into their investment process.

Concurrent to the low-carbon investing trend has been the adoption of factor-based asset allocation by institutional investors. Institutional investors who are implementing factor-based investing into their core equity allocation and who wish to align their entire investment process with low-carbon initiatives may need a total portfolio management approach, in which metrics related to carbon risk are integrated with signals from traditional risk factors. As such, there is a clear need in the market for studies that examine the impact of carbon risk integration with traditional factor portfolios.

Therefore, the debate at this juncture centers more on how imminently carbon risk is priced and thus to what degree market participants should position their existing portfolios. As a starting point for carbon-awareness investing, knowing the carbon footprint of a given portfolio is required. However, carbon footprint measures only part of the carbon-pricing risk and is not forward looking[1] in providing a complete estimate of carbon risk exposure.

For various reasons, including data availability and history, as well as the focus of the paper being to demonstrate portfolio implications of incorporating carbon-related metrics, our paper adopts a simpler approach by examining carbon risk through a carbon-efficiency lens.

In this paper, we argue that a pure, unconstrained, carbon-efficient portfolio outperforms a carbon-inefficient portfolio, as well as the underlying benchmark, on an absolute return basis, but underperforms on a risk-

[1] Bernick, Libby, Bullock, Steven, and Lord, Rick, "Carbon Pricing: Discover Your Blind Spots on Risk and Opportunity," Trucost, Jan. 17, 2018.

adjusted basis due to the portfolio having higher volatility. Moreover, we discuss how the carbon-efficient portfolio exhibits unintended sector and factor biases. Using the correlation of carbon intensity with style factors, we demonstrate a stylized framework in which carbon-efficient portfolios (both unconstrained and sector relative) can be combined with traditional risk factors to lower carbon intensity while maintaining the target factor exposure.

Through this analysis, we merge two powerful trends that are shaping the investment industry, and we provide a framework that can be used by institutional investors who wish to be sustainability-driven while focusing on achieving risk/return profiles that are specified in their investment mandates. We show that carbon-efficient factor portfolios can be a meaningful part of the core equity strategic and tactical asset allocation process.

The framework we have provided in our paper is by no means exhaustive. There are numerous ways to achieve decarbonized factor portfolios, each with its own tradeoffs and unique characteristics. Hence, in subsequent papers, we intend to explore additional case studies and provide stylized examples through which advantages and disadvantages of each approach can be further understood.

CURRENT CARBON INVESTING LANDSCAPE

There are USD 70 trillion of assets represented by the 1,700 signatories of the Principles for Responsibility.

As of April 2017, there are USD 70 trillion of assets represented by the 1,700 participants that have signed on to the Principles for Responsible Investment (PRI) and are committed to implementing the principles into their investment processes.[2] Signing the PRI recognizes that integrating environmental, social, and governance (ESG) considerations is part of their fiduciary responsibility, and that integrating carbon criteria specifically is paramount, given that carbon risk is not fully priced into market valuations. The past few years have witnessed market participants and asset owners increasingly engaging in different ESG investing strategies, ranging from exclusionary practices, to full ESG integration, to impact investing.

A number of initiatives have sought to measure carbon risks more effectively, perhaps the most influential being the Task Force on Climate-related Financial Disclosures (TCFD). In 2015, the Financial Stability Board (FSB) set up the task force, chaired by Michael Bloomberg, with the goal of drafting recommendations for climate-related financial disclosures that are consistent, comparable, reliable, clear, and efficient. The TCFD's report was released in June 2017, and it is expected to prove instrumental in helping investors understand the risks and opportunities posed to their portfolios by the transition to a low-carbon economy. As the TCFD's report

[2] Principles for Responsible Investment Annual Report 2017; http://annualreport.unpri.org/

encourages companies to make disclosures, it is hoped that these disclosures will end up in mainstream-integrated financial reports, rather than in sustainability reports, whereby audit committees and senior executives will then get involved.

So far, carbon prices have already been implemented in 40 countries and 20 cities and regions.[3] Research by Trucost[4] estimates that average carbon prices could increase more than sevenfold to USD 120 per metric ton by 2030, as regulations aim to limit the average global temperature increase to 2 degrees Celsius in accordance with the Paris Agreement. In response to this, Trucost has created a carbon pricing tool designed to help companies estimate internal carbon prices by modeling the progressive tightening of the spread between carbon prices today and in the future, considering science-based price scenarios and national climate change commitments. If a company understands the true cost of carbon, it can be empowered to make better business decisions to hedge against carbon exposure.[5]

Research by Trucost estimates that average carbon prices could increase more than sevenfold to USD 120 per metric ton by 2030, as regulations aim to limit the average global temperature increase to 2 degrees Celsius in accordance with the Paris Agreement.

From a regulatory perspective, in regard to the investing arena, there is a growing movement to support the case for carbon-based investing. France's new Energy Transition Law, Article 173, came into effect in 2016 and goes beyond climate policy reporting, extending to mandatory ESG disclosure. The law mandates the disclosure of climate-change-related risks by listed companies and financial institutions, as well as the alignment of investment portfolios with French and international climate policies.

In the U.S., the Department of Labor's ruling on ESG for ERISA plans in 2015 stating that "pension fund fiduciaries can now consider material ESG issues facing companies in their investment portfolios"[6] has lifted limitations and enabled greater ESG integration into the investing process. Finally, the International Standards Organization (ISO), the world's largest voluntary standards board, has embarked on a program to develop official guidelines on climate finance, which could include the first internationally accepted certification of climate performance and alignment with the 2 degree Celsius emissions target.

Lastly, according to a new PRI-Novethic survey released in September 2017, which surveyed 1,200 investors on investor action on climate change, global investors believed that more innovation was needed in investment

[3] Carbon Pricing Leadership Coalition," Carbon Pricing in Action," 2017

[4] Trucost Analysis OECD/IEA. 2017. Chapter 2 of Perspectives for the energy transition – investment needs for a low-carbon energy system. http://www.irena.org/DocumentDownloads/Publications/Perspectives_for_the_Energy_Transition_2017.pdf; OECD (2016), Effective Carbon Rates: Pricing CO2 through Taxes and Emissions Trading Systems, OECD Publishing, Paris.http://dx.doi.org/10.1787/9789264260115-en

[5] Trucost, 2017, "The Corporate Carbon Pricing Tool"

[6] Employee Benefits Security Administration, U.S. Labor Department, October 2015 https://www.dol.gov/opa/media/press/ebsa/ebsa20152045.htm

strategies and products associated with climate change to affect the emissions curve by 2020.[7] Therefore, incorporating evidence-based investing strategies with carbon awareness may help fill that need for more innovative and appropriate climate-related finance solutions.

LITERATURE REVIEW

In recent years, a number of studies have been published analyzing the carbon efficiency of companies and whether more carbon-efficient portfolios are associated with improved financial returns.

In 2017, In, Park, and Mon used a firm's carbon emission data from Trucost and found that carbon-efficient firms had lower book-to-market ratios, higher ROA, higher Tobin's Q, higher free cash flows and cash holdings, higher coverage ratios, lower leverage ratios, and higher dividend payout ratios.

In 2015, Puopolo, Teti, and Milani used data from 2009 to 2014 from *Newsweek's* Green Rankings database, which ranks the 500 largest publicly traded companies based on their environmental performance, in a CAPM and a Fama-French three-factor model to assess the return premium generated by the green-based factor.[8] Their study showed that there was no linear relationship between a firm's green performance and its financial performance. It should be noted that the limited time period of analysis may be an issue in the results, and the brevity of historical data is a global ESG issue that affects the results of any ESG research.

In 2017, In, Park, and Monk examined the relationship between firm-level carbon intensity, company characteristics, and stock market returns based on U.S. firms from 2005 to 2015. They used a firm's carbon emission data from Trucost and then divided it by the firm's revenue to get a normalized carbon intensity number to be used in constructing the efficient minus inefficient (EMI) portfolio.

After applying the Fama-French five-factor model, the authors found that carbon-efficient firms had lower book-to-market ratios, higher ROA, higher Tobin's Q, higher free cash flows and cash holdings, higher coverage ratios, lower leverage ratios, and higher dividend payout ratios. In addition, efficient firms exhibited a large positive cumulative return post-2009, and the EMI portfolio had explanatory power that was independent of well-known risk factors such as size, value, and momentum.[9]

In 2011, Günther, Hoppe, and Endrikat conducted an analysis of 274 empirical studies on the relationship between corporate environmental performance (CEP) and corporate financial performance (CFP). Their research concluded that considering all statistically significant results, there

7 Novethic, "Investor Action on Climate Change," September 2017.

8 Puopolo, G.W., Teti, E., and Milani, V., "Does the market reward for going green?," Journal of Management Development, Vol. 34, Issue 6, pp.729-742, 2015.

9 In, S.Y., Park, K.Y., and Monk, A., "Is 'Being Green' Rewarded in the Market? An Empirical Investigation of Decarbonization Risk and Stock Returns," International Association for Energy Economics, Singapore Issue 2017, pp.46-48, June 19, 2017.

is a ratio of 175:27 for positive to negative results, which strongly supports the hypothesis for a positive relationship between CEP and CFP.[10]

Lastly, in 2016, Andersson, Bolton, and Samama posited that using decarbonized indices allows passive long-term institutional investors the ability to hedge against climate risk and take advantage of a currently mispriced risk factor (carbon risk) in financial markets. Their recommendation for constructing the decarbonized index goes beyond a simple divestment policy, and instead it recommends divestment plus optimization to minimize tracking error to the reference benchmark. In designing the decarbonized index, their research highlights the benefits of a sector-neutral filtering approach in removing high carbon intensity stocks, in addition to normalized carbon intensity metrics.[11]

Contrary to prior carbon-awareness investing research, which aimed to uncover whether carbon awareness was a return-enhancing endeavor, Andersson, Bolton, and Samama's stance is more direct. Their view is based on the point that the market has not fully priced in carbon risk, but that the day of reckoning will come. They also highlight the regulatory, policy, governmental, and market shifts that will expedite the realization of carbon risk pricing.

Up to this point, most existing published research (with the exception of Andersson, Bolton, and Samama) has focused on whether carbon awareness has had a positive performance impact. Our paper contributes to the existing literature by examining the portfolio implications of incorporating carbon risk into the investment process. In particular, we focus on the risk aspect of portfolio management, since market participants are looking to understand how carbon metrics interact with their existing portfolios.

Over the past decade, factor-based investing has emerged as one of the most powerful trends reshaping the asset management industry.

CARBON RISK INTEGRATION WITH TRADITIONAL STYLE FACTORS

Over the past decade, factor-based investing has emerged as one of the most powerful trends reshaping the asset management industry. Investors—retail and institutional alike—are increasingly adopting a factor-based asset allocation approach to their investment process. As such, assets tied to factor-based strategies have tripled in the past five years—starting from USD 200 billion at the end of 2011, reaching USD 600 billion

[10] Günther, E., Hoppe, H., and Endrikat, J., "Corporate financial performance and corporate environmental performance: A perfect match?," Journal of Environmental Law and Policy, Vol. 34, pp.279-296, September 2011.

[11] Andersson, M., Bolton, P., and Samama, F., "Hedging Climate Risk," Financial Analysts Journal, Vol. 72, Number 3, pp.13-32, CFA Institute, May/June 2016.

by the end of 2016, and they are now expected to top USD 1 trillion by the end of 2018.[12]

As noted earlier, for institutional investors who are already implementing factor-based investing and who wish to align their entire investment process with low-carbon initiatives, a study of the interaction between carbon risk and traditional well-established risk factors is needed. This is because there may be common risk drivers behind carbon-efficient companies and factor portfolio constituents that need to be more fully understood. This understanding will ultimately help portfolio managers be better aware of the results of combining carbon- and factor-based investing, and more importantly, this education will promote better adoption of these strategies.

Data and Methodology

Carbon intensity data were provided by Trucost, part of S&P Dow Jones Indices. We use companies' carbon intensity to capture firm-level carbon efficiency.

The underlying universe for our study is the S&P United States LargeMidCap. To avoid survivorship bias, we included companies currently and historically in the benchmark. By doing so, we ensured that the back-tested results would likely not suffer from upward performance bias. Compustat is the main data source for company-level fundamental data. To prevent look-ahead bias, the fundamental data were appropriately lagged. Stock-level total return data (including both dividend and price return) were provided by S&P Dow Jones Indices.

Carbon intensity data were provided by Trucost, part of S&P Dow Jones Indices. The coverage of carbon data has improved over time. In May 2007, carbon intensity data covered about 80% of the companies in the S&P U.S. LargeMidCap universe. By January 2009, the coverage had improved to an average of 90% or more. In consideration of data availability, our back-tested period spans from May 31, 2007, to Dec. 31, 2017.

To minimize the impact of outliers, raw fundamental factor and individual carbon intensity scores were first winsorized. Then, z-scores were calculated using the means and standard deviations of the corresponding factors within the U.S. large- and mid-cap universe for each rebalancing period. Please refer to Appendix A for more details on factor definitions and z-score computation.

We use companies' carbon intensity to capture firm-level carbon efficiency. Individual company carbon intensity is defined as greenhouse gas (GHG) emissions measured in tons of carbon dioxide equivalent per USD 1 million of revenue (CO_2e/USD 1 million). This measure of carbon intensity includes direct and first-tier indirect emissions over revenue. Direct GHG emissions are generated from companies' own operation or production processes. First-tier indirect emissions are from companies' supply chains,

[12] Das, A. and Pioch, A., Legal and General Investment Management, "The Rise of Factor Based Investing," May 2017.

such as the supply of materials and equipment, business travel, and utilities. In our paper, we define a carbon-efficient company as a company that has lower carbon intensity, all else being equal. Likewise, a carbon-efficient portfolio means a portfolio that has lower aggregated carbon intensity.

Carbon intensity had a wide range among the 11 sectors due to their business operations or production processes.

We started by comparing carbon intensity by GICS sector. Within a sector, company-level carbon intensity data were averaged every three months to match portfolio rebalance frequencies during the back-tested period. As shown in Exhibit 1, carbon intensity had a wide range among the 11 sectors due to their business operations or production processes. The financials sector had the lowest carbon intensity at 44 tons of CO_2e/USD 1 million. On the other hand, the utilities sector had the highest carbon intensity at 3,715 tons of CO_2e/USD 1 million. Similar trends were found for cap-weighted carbon intensity by sector, which are listed in Appendix B.

Exhibit 1: Summary Statistics of Carbon Intensity by Sector

GICS SECTOR	CARBON INTENSITY (CO_2e/USD 1 MILLION)
Consumer Discretionary	93
Consumer Staples	274
Energy	639
Financials	44
Health Care	59
Industrials	248
Information Technology	63
Materials	916
Real Estate	92
Telecommunication Services	55
Utilities	3715

Source: S&P Dow Jones Indices LLC. Data as of Dec. 31, 2017. Table is provided for illustrative purposes.

The bottom-up approach was used to form carbon-efficient quintile portfolios. We first sorted the stocks by their individual carbon intensity, their style factors, or a combination of both, then we divided the universe into five groups. The quintile portfolios were rebalanced quarterly after the close of the third Friday in March, June, September, and December for the whole back-tested period from May 31, 2007, to Dec. 31, 2017.

Quintile portfolios were both market-cap-weighted and equal-weighted for a robustness check. Market-cap-weighted portfolios were subject to the following constraints.

- The maximum weight was 5% and the minimum weight was 0.05% for an individual company.
- Excess weights were redistributed in proportion to the market cap to other companies within the same sector when possible.

- For certain quintiles, excess weights were redistributed to other sectors when excess weights couldn't be redistributed within the same sector due to a limited number of companies.

In this paper, we primarily analyze the results of cap-weighted portfolios, but the equal-weighted results are presented in Appendix C to demonstrate the robustness of our analysis.

Unconstrained Carbon-Efficient Portfolios

The most carbon-efficient portfolio, Quintile 1, underperformed most of its peers, except for Quintile 5 and the underlying benchmark, on an absolute return basis. It also had the highest volatility among all the portfolios, thereby resulting in the lowest risk-adjusted return.

In this section, we ranked stocks in the whole universe (across sectors) based on individual companies' carbon intensity to form quintile portfolios. Exhibit 2 shows the risk/return profiles of carbon-efficiency-ranked quintile portfolios. The most carbon-efficient portfolio, Quintile 1, underperformed most of its peers, except for Quintile 5 and the underlying benchmark, on an absolute return basis. It also had the highest volatility among all the portfolios, thereby resulting in the lowest risk-adjusted return.

The data highlight that, while investing in a pure, carbon-efficient portfolio achieved the objective of lowering the carbon intensity of the investment portfolio with returns that were modestly better than the underlying benchmark, the portfolio was inferior from a risk-efficiency perspective.

We suspect that unconstrained carbon-efficiency portfolios may have large sector and risk factor biases relative to the underlying benchmark, and they may be unintentionally taking on large active bets for which they are not compensated.

The average sector weights of Quintile 1 showed that, on average, it had significant overweight in the financials sector, with an average weight of 45.29%. The portfolio also had substantial underweight in the energy, consumer staples, and industrials sectors. The overweight in financials contributed substantially to the negative active returns of the portfolio relative to the benchmark (see Exhibit 3). From June 2007 to December 2017, the allocation to the financials sector detracted an annualized return of approximately -2.39% from the portfolio's performance versus 0.43% for the benchmark on a monthly average basis.

Exhibit 2: Risk/Return Profiles of Unconstrained Carbon-Efficiency-Ranked Quintile Portfolios

CATEGORY	QUINTILE 1	QUINTILE 2	QUINTILE 3	QUINTILE 4	QUINTILE 5	S&P UNITED STATES LARGEMIDCAP
Annualized Return (%)	9.30	9.84	11.24	9.42	7.85	8.99
Annualized Risk (%)	20.71	16.07	14.47	14.41	15.07	14.94
Return/Risk	0.45	0.61	0.78	0.65	0.52	0.60
Average Carbon Intensity (CO_2e/USD 1 Million)	14	40	78	202	1525	307

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

Exhibit 3: Sector Contribution to Active Return of Unconstrained Carbon-Efficient Portfolio

SECTOR WEIGHTS	BENCHMARK SECTOR WEIGHTS (%)	BENCHMARK CONTRIBUTION TO RETURN (%)	UNCONSTRAINED CARBON-EFFICIENT PORTFOLIO		
			PORTFOLIO WEIGHT (%)	ACTIVE SECTOR WEIGHTS (%)	PORTFOLIO CONTRIBUTION TO ACTIVE RETURN (%)
Consumer Discretionary	11.31	1.55	13.29	1.98	0.71
Consumer Staples	10.39	1.07	0.00	-10.39	-
Energy	10.47	0.33	0.00	-10.47	-
Financials	15.90	0.43	61.19	45.29	-2.39
Health Care	13.11	1.37	6.67	-6.44	0.49
Industrials	10.10	0.94	0.45	-9.65	-0.03
Information Technology	19.34	2.55	18.04	-1.31	1.49
Materials	3.28	0.29	0.00	-3.28	-
Real Estate	0.36	0.01	0.13	-0.23	0.00
Telecommunication Services	2.38	0.23	0.23	-2.16	0.03
Utilities	3.34	0.22	0.00	-3.34	-
Unassigned	0.01	0.00	-	-0.01	-
Total	**100**	**8.99**	**100**	**-**	**0.31**

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.
Note: Contribution to return or active return is on a monthly average basis (annualized).

We formed sector relative carbon-efficient portfolios to examine whether the resulting portfolios display improved risk efficiency and lower sector and risk factor biases.

Sector Relative Carbon-Efficient Portfolios

In this section, we form sector relative carbon-efficient portfolios to examine whether the resulting portfolios display improved risk efficiency and lower sector and risk factor biases.

To form sector relative portfolios, we grouped securities in the universe based on their GICS classification. We then ranked them within each sector by carbon intensity, with lower carbon intensive firms ranking better, and then we divided them into quintiles.[13] The top quintiles from each GICS sector, comprising the most carbon-efficient firms, were then aggregated to form the sector relative Quintile 1 portfolio. For example, Quintile 1 is a pool of Q1 consumer discretionary companies, plus Q1 financials companies, plus Q1 utilities companies, etc. For each quintile group, we built a cap-weighted portfolio subject to the constraints in the “Data and Methodology” section. The remaining Quintile 2-5 portfolios were also formed in that manner. At the end, we had five portfolios (Q1, Q2, Q3, Q4, and Q5) for the whole universe.

We can see that forming sector relative carbon-efficiency portfolios resulted in a tradeoff (see Exhibit 4). The most carbon-efficient portfolio, Quintile 1, had similar risk-adjusted returns to Quintiles 2, 3, and 5, but higher risk-adjusted returns than Quintile 4 and the benchmark. Quintile 1 also had higher carbon intensity than its unconstrained counterpart. For example, the unconstrained Quintile 1 portfolio, on average, had 14 tons of CO_2e/USD 1 million, whereas the sector relative Quintile 1 portfolio increased substantially to 66 tons of CO_2e/USD 1 million. Nevertheless, the carbon reduction relative to the underlying benchmark was still substantial, at nearly 80%.

The sector relative carbon-efficient portfolio displayed minor sector deviations from the underlying benchmark. The sector allocation effect was positive and contributed to its active return over the benchmark.

Exhibit 4: Risk/Return Profiles of Sector Relative Carbon-Efficiency-Ranked Quintile Portfolios

CATEGORY	QUINTILE 1	QUINTILE 2	QUINTILE 3	QUINTILE 4	QUINTILE 5	S&P UNITED STATES LARGEMIDCAP
Annualized Return (%)	10.65	10.87	10.15	7.78	9.55	8.99
Annualized Risk (%)	16.19	16.35	15.03	15.59	14.45	14.94
Return/Risk	0.66	0.66	0.68	0.50	0.66	0.60
Average Carbon Intensity (CO_2e/USD 1 Million)	66	121	215	391	815	307

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

In addition to carbon intensity reduction, the sector relative carbon-efficient portfolio displayed minor sector deviations from the underlying benchmark. During the back-tested period, average active sector weights maximized at about 5%. Earlier, we showed that the unconstrained carbon-efficient portfolio underperformed the underlying benchmark in terms of risk-adjusted return because of its active sector bets (with a sector allocation effect of annualized underperformance of -1.51% on a monthly average basis; see Exhibit 6). With the sector relative carbon-efficient portfolio, the sector allocation effect was positive (with an annualized return of 0.32% on

[13] Each sector now will have five groups, resulting in $5x11 = 55$ quintile groups.

a monthly average basis; see Exhibit 6) and contributed positively to its active return over the benchmark.

Exhibit 5: Sector Contribution to Active Return of Sector Relative Carbon-Efficient Portfolio

SECTOR WEIGHTS	BENCHMARK SECTOR WEIGHTS (%)	BENCHMARK CONTRIBUTION TO RETURN (%)	SECTOR RELATIVE CARBON-EFFICIENT PORTFOLIO		
			PORTFOLIO WEIGHT (%)	ACTIVE SECTOR WEIGHTS (%)	PORTFOLIO CONTRIBUTION TO ACTIVE RETURN (%)
Consumer Discretionary	11.31	1.55	16.16	4.85	0.68
Consumer Staples	10.39	1.07	15.43	5.04	0.20
Energy	10.47	0.33	10.32	-0.15	-0.55
Financials	15.90	0.43	11.48	-4.42	-0.52
Health Care	13.11	1.37	17.03	3.92	0.79
Industrials	10.10	0.94	7.84	-2.26	-0.14
Information Technology	19.34	2.55	14.13	-5.21	1.10
Materials	3.28	0.29	2.68	-0.60	0.06
Real Estate	0.36	0.01	0.48	0.12	-0.00
Telecommunication Services	2.38	0.23	0.97	-1.42	0.13
Utilities	3.34	0.22	3.49	0.15	-0.08
Unassigned	0.01	0.00	-	-0.01	-
Total	**100**	**8.99**	**100**	**-**	**1.66**

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007 to Dec. 31, 2017. Index performance based on total return in USD. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.
Note: Contribution to return or active return is on monthly average basis (annualized).

Both unconstrained and sector relative carbon-efficient portfolios historically displayed positive active exposure to value and price volatility factors, as well as negative active exposure to yield and size factors.

Exhibit 6: Performance Attribution in Monthly Average Annualized Return

PORTFOLIO	ALLOCATION EFFECT (%)	SELECTION + INTERACTION EFFECT (%)	TOTAL EFFECT (%)
Unconstrained Carbon-Efficient Portfolio	-1.51	1.82	0.31
Sector Relative Carbon-Efficient Portfolio	0.32	1.34	1.66

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007 to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.
Note: Contribution to return or active return is on monthly average basis (annualized).

Active Risk Exposures and Risk Decomposition of Carbon-Efficient Portfolios

Both unconstrained and sector relative carbon-efficient portfolios historically displayed positive active exposure to value and price volatility factors, as well as negative active exposure to yield and size factors (see Exhibit 7).[14]

[14] We use the Northfield U.S. Fundamental Risk Model to estimate the risk exposure.

Unlike its unconstrained counterpart, the sector relative portfolio had positive active exposure to earnings growth and momentum, with negative active exposure to leverage and earnings variability (metrics that are often used to measure earnings quality). Therefore, during the back-tested period, the sector relative carbon-efficient portfolio was more exposed to the quality factor than the unconstrained portfolio on average.

Exhibit 7: Active Risk Exposures of Carbon-Efficient Portfolios

FACTOR		AVERAGE FACTOR RETURN (%, MONTHLY)	S&P UNITED STATES LARGEMIDCAP	UNCONSTRAINED CARBON-EFFICIENT PORTFOLIO			SECTOR RELATIVE CARBON-EFFICIENT PORTFOLIO		
			AVERAGE EXPOSURE (MONTHLY)	AVERAGE EXPOSURE (MONTHLY)	AVERAGE ACTIVE EXPOSURE (MONTHLY)	AVERAGE FACTOR IMPACT (MONTHLY)	AVERAGE EXPOSURE (MONTHLY)	AVERAGE ACTIVE EXPOSURE (MONTHLY)	AVERAGE FACTOR IMPACT (MONTHLY)
Market	Beta	0.65	1.04	1.25	0.22	0.20	1.07	0.04	-0.02
Value	Earnings/Price	0.02	0.35	0.49	0.13	0.00	0.32	-0.04	0.00
	Revenue/Price	0.09	-0.24	-0.24	0.00	0.00	-0.04	0.20	0.02
	Book/Price	-0.22	-0.33	0.22	0.55	-0.12	-0.33	0.00	0.00
Earnings Growth	EPS Growth Rate	0.01	0.01	-0.05	-0.06	0.01	0.09	0.08	0.01
Yield	Dividend Yield	0.12	0.20	0.00	-0.20	-0.03	-0.06	-0.26	-0.02
Liquidity	Trading Activity	0.04	-0.08	0.04	0.12	0.01	-0.07	0.01	0.00
Volatility	Price Volatility	-0.56	-0.61	-0.42	0.19	-0.09	-0.54	0.07	-0.04
Momentum	Relative Strength	0.06	0.04	0.00	-0.04	0.08	0.07	0.03	0.05
Leverage	Debt/Equity	-0.12	0.17	0.41	0.24	-0.03	0.00	-0.17	0.02
Earnings Stability	Earnings Variability	-0.14	-0.40	-0.44	-0.04	-0.01	-0.68	-0.28	0.04
Size	Log of Market Cap	-0.12	2.21	2.04	-0.16	0.03	1.92	-0.28	0.03
Industry	-		1.00	1.00	0.00	-0.03	1.00	0.00	-0.02

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

The risk decomposition analysis also showed that the carbon-efficient portfolio, on average, had 69% of the total risk coming from common factor risk, with the remaining coming from asset-specific risk. In contrast, the sector relative carbon-efficient portfolio had nearly half the percentage of total risk stemming from common factor risk, at 33%, with the remaining coming from asset-specific risk (see Exhibit 8).

The results confirmed that unconstrained carbon-efficient portfolios had significant unintended risk factor tilts that were not being compensated. The sector relative carbon-efficient portfolio, on the other hand, reduced unrewarded systematic risks through better sector diversification. From a risk management perspective, the sector relative portfolio freed up the available risk budget, while simultaneously meeting the carbon reduction objective.

Exhibit 8: Risk Decomposition of Carbon-Efficient Portfolios

PORTFOLIO	AVERAGE COMMON FACTOR RISK (% OF TOTAL RISK)	AVERAGE ASSET-SPECIFIC RISK (% OF TOTAL RISK)	AVERAGE TOTAL RISK (%)
Unconstrained Carbon-Efficient Portfolio	68.69	31.31	23.29
Sector Relative Carbon-Efficient Portfolio	32.66	67.34	19.50

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

CORRELATION OF CARBON INTENSITY AND TRADITIONAL RISK FACTORS

In this section, we examine the relationship of carbon intensity with traditional risk factors. For investors who are already implementing a factor-based asset allocation approach and who wish to incorporate carbon risk into their investment process, it is imperative that the interaction of carbon intensity with risk factors is understood.

We can see that more carbon-efficient (lower carbon intensity) companies tended to have lower financial leverage ratios, lower book-to-price ratios, and lower sales-to-price ratios, while displaying higher three-year sales per share (SPS) growth, higher return on equity (ROE), higher price volatility, and higher price momentum, which are all statistically significant at a 95% confidence level.

In accordance with our bottom-up approach to quintile portfolio construction, we first analyzed the firm-level correlation between the carbon intensity of securities in our test universe and 10 widely used factors in 4 investment styles (see Exhibit 9). We computed the cross-sectional correlation of carbon intensity to each factor for each rebalance during the back-tested period, and then we took the average of the cross-sectional correlations and calculated the t-statistics. This exercise enabled us to link carbon intensity with financial fundamentals.

We can see that more carbon-efficient (lower carbon intensity) companies tended to have lower financial leverage ratios, lower book-to-price ratios, and lower sales-to-price ratios, while displaying higher three-year sales per share (SPS) growth, higher return on equity (ROE), higher price volatility, and higher price momentum, which are all statistically significant at a 95% confidence level. The findings are in line with Monk and Park (2017) who also noted that carbon-efficient firms had lower book-to-market ratios, higher ROA, higher Tobin's Q, higher free cash flows and cash holdings, higher coverage ratios, lower leverage ratios, and higher dividend payout ratios.

Exhibit 9: Cross-Sectional Correlation Company Carbon Intensity With 10 Style Factors

STYLES	STYLE FACTORS	CORRELATION (%)	CORRELATION T-STATISTICS
Quality	Financial Leverage Ratio	8.5	16.2
	ROE	-5.0	-9.2
	Balance Sheet Accruals Ratio	-0.7	-1.1
Low Volatility	Low Volatility	-17.9	-13.2
Growth	Three-Year Earnings Per Share Growth Over Price	-0.5	-0.9
	Three-Year SPS Growth	-11.0	-8.1
	12-Month Price Momentum	-3.9	-2.8
Value	Book-to-Price Ratio (B2P)	11.4	14.3
	Sales-to-Price Ratio (S2P)	2.8	6.2
	Earnings-to-Price Ratio (E2P)	1.9	1.8

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

To explore potential diversification benefits when integrating carbon intensity with style factors, we calculated forward return correlation of carbon-efficient portfolios and portfolios of four investment styles.

To explore potential diversification benefits when integrating carbon intensity with style factors, we calculated forward return correlation of carbon-efficient portfolios and portfolios of four investment styles—quality, low volatility, value, and growth.[15] For each factor, return was estimated by computing quintile return spread (the return from the top quintile portfolio minus the return from the bottom quintile portfolio), assuming a three-month holding period. We then calculated the correlation coefficient between the return spreads of the factor portfolios (see Exhibit 10).

Exhibit 10: Q1 to Q5 Return Spread Correlation Carbon-Efficiency With Risk Factors

FACTOR	CARBON EFFICIENCY	QUALITY	LOW VOLATILITY	GROWTH	VALUE
CARBON EFFICIENCY	1.00	-	-	-	-
QUALITY	-0.84	1.00	-	-	-
LOW VOLATILITY	-0.74	0.81	1.00	-	-
GROWTH	-0.68	0.81	0.74	1.00	-
VALUE	0.48	-0.60	-0.53	-0.72	1.00

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

We can see that the forward returns of quality, low volatility, and growth are negatively correlated with carbon-efficient portfolios, thereby providing potential diversification benefits when combined with carbon efficiency in a portfolio. On the other hand, the value factor is positively correlated with carbon efficiency, providing less diversification benefits.

[15] Please see Appendix A for factor definition and calculation.

INTEGRATING CARBON RISK WITH FACTOR PORTFOLIOS

Based on the correlation of carbon efficiency with traditional risk factors, we analyzed the integration of carbon with the four styles identified in the previous section. We compared the hypothetical carbon-integrated portfolios (factor plus carbon efficiency and sector relative factor plus carbon efficiency) to the unconstrained carbon-efficient portfolio, the factor portfolio, and the underlying benchmark.

Based on the correlation of carbon efficiency with traditional risk factors, we analyzed the integration of carbon to the four styles.

We incorporated carbon risk with each factor by computing an integrated carbon factor score, which is defined as the equal-weighted combination of carbon efficiency and the style factor score. Our approach is one of the many ways carbon risk can be integrated into existing equity portfolios.

Risk, Return, and Carbon Intensity Analysis

Integrating carbon risk with factor portfolios resulted in a tradeoff between reduction in carbon intensity and lower risk-adjusted returns for all factors except growth.

For example, the quality + carbon efficiency portfolio had lower risk-adjusted returns (0.78) than the quality portfolio (0.80). However, the carbon intensity of the quality + carbon efficiency portfolio was reduced to 19% of the underlying universe. The sector relative quality + carbon efficiency portfolio also outperformed the benchmark on a risk-adjusted basis, albeit with a lower Sharpe ratio than its quality and quality plus carbon efficiency counterparts.

Similarly, the value and low volatility portfolios exhibited higher carbon intensity than the underlying benchmark. The low volatility portfolio, in particular, appeared to be the most carbon intensive, with a carbon intensity that was on average 1.6 times that of the underlying universe. For market participants who seek to earn a low volatility factor premium, the carbon intensity of a low volatility portfolio may unintentionally expose them to carbon regulatory risk. By combining a low volatility portfolio with carbon efficiency, the resulting portfolio still achieved its core objective of reducing the realized portfolio volatility, while lowering the carbon intensity to 25%-32% of the original low volatility portfolio.

Combining the value factor with carbon efficiency may not achieve the optimal outcome, given the positive forward return correlation between the two (see Exhibit 10). We can see that the value + carbon efficiency portfolio underperformed the value portfolio, as well as the market. On the other hand, the sector relative value + carbon efficiency portfolio had higher risk-adjusted returns than its unconstrained counterpart, indicating that sector bets may have contributed to the underperformance.

Forming a portfolio of securities that are carbon efficient and display growth-oriented characteristics appears to provide the most risk-efficient portfolio. Both unconstrained and sector relative growth + carbon efficiency portfolios outperformed the growth portfolio and the market on a risk-adjusted basis, while achieving a carbon intensity reduction of 37%-52%.

Exhibit 11: Risk/Return and Carbon Intensity Analysis of Factor Portfolios

PORTFOLIO	ANNUALIZED RETURN (%)	ANNUALIZED RISK (%)	RETURN/RISK	AVERAGE CARBON INTENSITY (CO_2e/USD 1 MILLION)
Carbon-Efficient Portfolio	9.30	20.71	0.45	14
Quality	11.23	14.02	0.80	163
Quality + Carbon Efficiency	11.89	15.29	0.78	58
Quality + Carbon Efficiency (SR)	10.20	14.83	0.69	100
Low Volatility	8.92	10.87	0.82	504
Low Volatility + Carbon Efficiency	9.19	11.36	0.81	124
Low Volatility + Carbon Efficiency (SR)	9.00	12.26	0.73	161
Value	9.03	20.31	0.44	314
Value + Carbon Efficiency	7.88	21.11	0.37	62
Value + Carbon Efficiency (SR)	9.01	18.63	0.48	114
Growth	10.26	15.87	0.65	202
Growth + Carbon Efficiency	11.03	15.60	0.71	74
Growth + Carbon Efficiency (SR)	10.37	15.50	0.67	105
S&P United States LargeMidCap	8.99	14.94	0.60	307

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

Carbon-Risk-Integrated Factor Portfolios Maintain Target Factor Exposure

In addition to lowering carbon intensity, the resulting combined portfolios do not materially sacrifice their exposure level to the target factor.

In addition to lowering carbon intensity, the resulting combined portfolios do not materially sacrifice their exposure level to the target factor. In the prior section, we showed the tradeoff between risk/return characteristics and the reduction in average carbon intensity. In this section, we examine the factor exposure of carbon-risk-integrated portfolios. We compared the weighted average style z-score of the integrated portfolios to the pure factor portfolio, as well as the broad benchmark (see Exhibit 12).

We can see that combining carbon efficiency with factor portfolios reduced the factor exposure, as measured by the weighted average z-score. In order to assess whether the differences in exposure are statistically significant or not, we also performed two sample t-tests and showed the calculated t-statistics (the critical value of 95% confidence level is 1.99).

We can see that the t-statistics were statistically significant for carbon-integrated low volatility portfolios, as well as for the sector relative value portfolio. Therefore, we rejected the null hypothesis and concluded that the lowered factor exposures we observed in low volatility + carbon efficiency portfolios is meaningfully different from that in the low volatility portfolios. This finding shows that further research is needed on additional portfolio construction techniques to effectively combine carbon efficiency with low volatility portfolios.

Based on the results, we can also confirm that carbon risk can be effectively integrated with quality, growth, and value (unconstrained) factor portfolios without jeopardizing the carbon intensity reduction or factor exposure goals.

Exhibit 12: Factor Exposure of Carbon-Risk-Integrated Portfolios

FACTOR EXPOSURE (WEIGHTED AVERAGE Z-SCORE)	FACTOR	FACTOR + CARBON EFFICIENCY	FACTOR + CARBON EFFICIENCY (SR)	S&P UNITED STATES LARGEMIDCAP
Quality	0.47	0.47	0.45	0.03
T-Statistic	-	0.10	0.72	-
Low Volatility	1.64	1.52	1.25	0.43
T-Statistic	-	5.46	15.49	-
Value	0.88	0.82	0.74	-0.02
T-Statistic	-	1.19	3.42	-
Growth	0.84	0.79	0.77	0.05
T-Statistic	-	1.29	1.57	-

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

COMBINING CARBON EFFICIENCY WITH FACTORS CHANGES RISK COMPOSITION MIX

On average, carbon-integrated factor portfolios (with the exception of low volatility) tended to have lower common factor risk and higher asset-specific risk.

An effective portfolio risk management process requires being aware of what factor bets have been intentionally taken and of those bets, which have been rewarded. As we showed earlier, unconstrained carbon-efficient portfolios had unintended factor biases, with approximately 70% of the portfolio's total risk coming from systematic risk. Integrating carbon efficiency with factor portfolios altered the risk composition. On average, carbon-integrated factor portfolios, with the exception of low volatility, tended to have lower common factor risk and higher asset-specific risk. Sector relative portfolios had lower common factor risk than their unconstrained counterparts.

We found that combining carbon efficiency with low volatility, however, increased the percentage of total risk that stems from systematic risk in comparison with the unconstrained carbon-efficient portfolio. We suspect the increase may stem from the fact that low volatility portfolios have a natural inclination toward defensive sectors such as utilities, which are carbon intensive, whereas carbon efficiency favors sectors such as financials. Hence, low volatility and carbon efficiency have different sector preferences that expose the combined portfolio to a higher common factor risk than the unconstrained carbon-efficient portfolio.

Exhibit 13: Risk Decomposition of Factor Portfolios

PORTFOLIO	AVERAGE COMMON FACTOR RISK (% OF TOTAL RISK)	AVERAGE ASSET SPECIFIC RISK (% OF TOTAL RISK)	AVERAGE TOTAL RISK (%)
Carbon-Efficient Portfolio	68.69	31.31	23.29
Quality	50.22	49.78	18.18
Quality + Carbon Efficiency	48.95	51.05	18.74
Quality + Carbon Efficiency (SR)	35.22	64.78	18.35
Low Volatility	83.72	16.28	15.26
Low Volatility + Carbon Efficiency	80.60	19.40	15.81
Low Volatility + Carbon Efficiency (SR)	67.54	32.46	16.75
Value	71.92	28.08	22.46
Value + Carbon Efficiency	73.58	26.42	22.87
Value + Carbon Efficiency (SR)	59.14	40.86	21.48
Growth	60.02	39.98	20.71
Growth + Carbon Efficiency	57.84	42.16	20.79
Growth + Carbon Efficiency (SR)	50.24	49.76	20.22

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Index performance based on total return in USD. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

In practice, many institutional investors seek diversified exposure to factors through a multi-factor portfolio. As such, in this section we present a stylized example of a hypothetical carbon-risk-integrated multi-factor portfolio.

A STYLIZED MULTI-FACTOR FRAMEWORK

Up to this point, we have only examined the impact of incorporating carbon risk with single-factor portfolios. The analysis is helpful in understanding the interaction of carbon risk with each of the factors and the resulting tradeoffs. In practice, many institutional investors seek diversified exposure to factors through a multi-factor portfolio. As such, in this section we present a stylized example of a hypothetical carbon-risk-integrated multi-factor portfolio.

We acknowledge that a multi-factor portfolio can be constructed in two different ways: as a portfolio consisting of single-factor portfolios or as an integrated mix in which each asset is assigned an overall score based on its style exposures.[16][17]

[16] Blitz, David, Roscovan, Viorel, and Vidojevic, Milan, "Mixed versus integrated multi-factor portfolios," Robeco Asset Management, December 2017.

For illustrative purposes, we adopted the latter in our construction of the multi-factor portfolio. For each security in our study universe we assigned a multi-factor score, which was calculated as an equal-weighted value based on value, quality, low volatility, and growth exposure. We then assigned a composite multi-factor + carbon efficiency score by equal weighting each security's multi-factor score and carbon-intensity score. The securities were then ranked by their composite scores and grouped into five quintiles with higher values ranking better. Each quintile portfolio was market-cap-weighted and rebalanced on a quarterly basis.

We present the results in Exhibit 14 using the Quintile 1 portfolio. The multi-factor portfolio had the highest risk-adjusted returns among all the portfolios studied, but it also had the highest carbon intensity, other than the low volatility portfolio. By combining the portfolio with carbon efficiency, the resulting portfolio reduced the carbon intensity significantly, by roughly 83%. Reducing the carbon intensity does not come at the expense of underperforming the market. The carbon-integrated portfolio (both unconstrained and sector relative) outperformed the market on risk-adjusted basis.

With respect to active factor bets, as shown in Exhibit 15, compared to the multifactor portfolio, the new carbon-integrated strategy had higher positive active exposure to earnings growth and momentum, as well as higher negative active exposure to earnings variability and leverage. It also exhibited lower positive active exposure to yield and lower negative active exposure to liquidity and price volatility.

Risk decomposition analysis shows that the carbon-risk-integrated multi-factor portfolio had a lower percentage of total risk coming from common factor risk than the carbon-efficient portfolio, as well as the multi-factor portfolio.

Risk decomposition analysis shows that the carbon-risk-integrated multi-factor portfolio had a lower percentage of total risk coming from common factor risk than the carbon-efficient portfolio, as well as the multi-factor portfolio. This is a desirable attribute because specific risks can be diversified away, while common factor risks are not afforded this luxury.

Exhibit 14: Risk/Return and Carbon Intensity Analysis of Multi-Factor Portfolios

CATEGORY	CARBON-EFFICIENT PORTFOLIO	MULTI-FACTOR	MULTI-FACTOR + CARBON EFFICIENCY	MULTI-FACTOR + CARBON EFFICIENCY (SR)	S&P UNITED STATES LARGEMIDCAP
Annualized Return (%)	9.30	9.55	9.93	8.64	8.99
Annualized Risk (%)	20.71	10.90	11.64	12.39	14.94
Return/Risk	0.45	0.88	0.85	0.70	0.60
Average Carbon Intensity	14	459	74	119	307

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

[17] Fitzgibbons, Shaun, Friedman, Jacques, Pomorski, Lukasz, and Serban, Laura, "Long-Only Style Investing: Don't Just Mix, Integrate," Journal of Investing, Forthcoming, AQR White Paper, Oct. 20, 2017.

Exhibit 15: Active Risk Exposures of Multi-Factor Portfolios

FACTOR		AVERAGE FACTOR RETURN (%, MONTHLY)	S&P UNITED STATES LARGEMIDCAP AVERAGE EXPOSURE (MONTHLY)	MULTI-FACTOR PORTFOLIO AVERAGE ACTIVE EXPOSURE (MONTHLY)	MULTI-FACTOR + CARBON-EFFICIENT PORTFOLIO AVERAGE ACTIVE EXPOSURE (MONTHLY)	MULTI-FACTOR + CARBON-EFFICIENT PORTFOLIO (SR) AVERAGE ACTIVE EXPOSURE (MONTHLY)
Market	Beta	0.65	1.04	-0.23	-0.16	-0.12
Value	Earnings/Price	0.02	0.35	0.20	0.17	0.19
	Revenue/Price	0.09	-0.24	0.13	0.09	0.15
	Book/Price	-0.22	-0.33	-0.05	-0.04	-0.10
Earnings Growth	EPS Growth Rate	0.01	0.01	-0.06	0.02	0.05
Yield	Dividend Yield	0.12	0.20	0.29	0.16	0.12
Liquidity	Trading Activity	0.04	-0.08	-0.30	-0.26	-0.20
Volatility	Price Volatility	-0.56	-0.61	-0.36	-0.29	-0.23
Momentum	Relative Strength	0.06	0.04	0.02	0.04	0.04
Leverage	Debt/Equity	-0.12	0.17	-0.01	-0.02	-0.13
Earnings Stability	Earnings Variability	-0.14	-0.40	-0.21	-0.33	-0.29
Size	Log of Market Cap	-0.12	2.21	0.22	0.23	0.17
Industry			1.00	0.00	0.00	0.00

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

Exhibit 16: Risk Decomposition Analysis of Multi-Factor Portfolios

PORTFOLIO	AVERAGE COMMON FACTOR RISK (% OF TOTAL RISK)	AVERAGE ASSET SPECIFIC RISK (% OF TOTAL RISK)	AVERAGE TOTAL RISK (%)
Carbon-Efficient Portfolio	68.69	31.31	23.29
Multi-Factor Portfolio	76.32	23.68	15.79
Multi-Factor + Carbon Portfolio	66.29	33.71	16.85
Multi-Factor + Carbon Portfolio (SR)	55.58	44.42	17.30

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance. SR stands for sector relative.

CONCLUSION

In recent years, discussions on climate change have progressed to the point of increasing the number of institutional investors that are seeking to align their investment outcomes in accordance with low-carbon initiatives. There are multiple ways in which decarbonized portfolios can be constructed. Our paper is written from the viewpoint of carbon-efficient portfolio construction. We demonstrated that sector relative, rather than unconstrained, carbon-efficient portfolios have more desirable attributes, such as higher risk efficiency, lower active sector bets, and lower uncompensated factor tilts. As such, we advocate forming sector relative carbon-efficient portfolios over unconstrained ones when portfolio decarbonization is the main goal.

We also recognize that many institutional investors, who have already adopted factor-based asset allocation, are looking to understand more about how carbon risk integration can interact with their existing portfolios. We showed that for integration with certain style factors (such as quality and growth), the carbon intensity of the resulting portfolios can be effectively reduced without sacrificing the desired target factor exposure. For integration with factors such as low volatility, the impact on desired portfolio-level factor exposure was shown to be statistically significant and merits further research on additional portfolio construction techniques.

APPENDIX A: STYLE FACTORS AND FUNDAMENTAL RATIO CALCULATIONS

For the four investment styles (quality, low volatility, value, and growth) the definitions are shown in Exhibit 17.

Exhibit 17: Investment Style Definitions

STYLES	STYLE FACTORS
Quality	A. Return on equity (ROE) B. Balance sheet accruals ratio (BSA; lower values are better) C. Financial leverage ratio (FLR; lower values are better)
Low Volatility	A. Inverse of volatility
Growth	A. Three-year change in earnings per share (excluding extra items) over price per share B. Three-year sales per share (SPS) growth rate C. Momentum (12-month % price change)
Value	A. Book value-to-price ratio (B2P) B. Earnings-to-price ratio (E2P) C. Sales-to-price ratio (S2P)

Source: S&P Dow Jones Indices LLC. Data as of Dec. 31, 2017. Table is provided for illustrative purposes.

As of the rebalancing reference date, fundamental ratios were calculated for each security in the index universe. They are defined as follows.

- **Return on Equity (ROE):** This is calculated as a company's trailing 12-month earnings per share (EPS) divided by its latest book value per share (BVPS).

$$\text{ROE} = \frac{\text{EPS}}{\text{BVPS}}$$

- **Balance Sheet Accruals (BSA) Ratio:** This is computed using the change of a company's net operating assets over the last year divided by its average net operating assets over the last two years.

$$\text{BSA} = \frac{\text{NOA}_t - \text{NOA}_{t-1}}{\frac{\text{NOA}_t + \text{NOA}_{t-1}}{2}}$$

- **Financial Leverage Ratio (FLR):** This is calculated as a company's latest total debt divided by its book value.

$$\text{FLR} = \frac{\text{Total Debt}}{\text{BVPS x Common Shares Outstanding}}$$

- **Volatility:** This is defined as the standard deviation of the security's daily price returns over the prior one year of trading days.

- **Three-Year Change in EPS Growth to Three-Year Price Return Ratio:** This is calculated as a company's three-year EPS compound annual growth rate (CAGR) divided by its three-year price return.

$$\text{EPS Growth to Price Return Ratio} = \frac{\text{3 Year EPS CAGR}}{\text{3 Year Price Return}}$$

- **Three-Year Sales per Share Growth Rate:** This is calculated as a company's three-year growth of sales per share (SPS).

$$\text{3 Year Sales Per Share Growth Rate} = \frac{(\text{SPS}_{\text{t}} - \text{SPS}_{\text{t}-3})}{\text{SPS}_{\text{t}-3}}$$

- **Momentum:** This is calculated as a company's12-month percent of price (P) change:

$$\text{Momentum} = \frac{(\text{P}_{\text{t}} - \text{P}_{\text{t}-12})}{\text{P}_{\text{t}-12}}$$

- **Book Value-to-Price Ratio:** This is calculated as a company's latest book value per share divided by its price.

$$\text{Book Value to Price} = \frac{\text{BVPS}}{\text{P}}$$

- **Earnings-to-Price Ratio:** This is calculated as a company's trailing 12-month earnings per share divided by its price.

$$\text{Earnings to Price} = \frac{\text{EPS}}{\text{P}}$$

- **Sales-to-Price Ratio:** This is calculated as a company's trailing 12-month sales per share divided by its price.

$$\text{Sales to Price} = \frac{\text{SPS}}{\text{P}}$$

Outlier Handling and Winsorization: Outlier fundamental ratios are winsorized to ensure that the average values used to calculate the overall component score are less distorted by extreme values. For a given fundamental variable, the values for all securities are first ranked in ascending order. Then, for securities that lie above the 97.5 percentile rank or below the 2.5 percentile rank, their value is set as equal to the value of the 97.5 percentile ranked or the 2.5 percentile ranked security, whichever is applicable.

Z-Score Computation: Computing a z-score is a widely adopted method of standardizing a variable in order to combine it with other variables that may have a different scale or unit of measurement. After winsorizing all the fundamental ratios, the z-score for each of the ratios for each security is calculated using the mean and standard deviation of the relevant variable within each of the index universes.

The z-score is calculated as follows:

$$z_\alpha = (x_\alpha - \mu_\alpha)/\sigma_\alpha$$

where:

z_α = Z-score for a given security
x_α = Winsorized variable for a given security
μ_α = Arithmetic mean of the winsorized variable in a given index universe, excluding any missing values
σ_α = Standard deviation of the winsorized variable in a given index universe

APPENDIX B: SUMMARY STATISTICS OF CARBON INTENSITY BY SECTOR (CAP-WEIGHTED)

Exhibit 18: Carbon Intensity by Sector (Cap-Weighted)

GICS SECTOR	CARBON INTENSITY (CO_2e/USD 1 MILLION)
Consumer Discretionary	73
Consumer Staples	204
Energy	576
Financials	47
Healthcare	65
Industrials	229
Information Technology	50
Materials	925
Real Estate	119
Telecommunication Services	66
Utilities	3926

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

APPENDIX C

Exhibit 19: Risk/Return Profiles of Unconstrained Carbon-Efficiency-Ranked Quintile Portfolios (Equal-Weighted)

CATEGORY	QUINTILE 1	QUINTILE 2	QUINTILE 3	QUINTILE 4	QUINTILE 5	S&P UNITED STATES LARGEMIDCAP
Annualized Return (%)	10.63	10.64	11.16	10.63	9.95	8.99
Annualized Risk (%)	21.12	16.34	17.33	17.38	16.24	14.94
Return/Risk	0.50	0.65	0.64	0.61	0.61	0.60
Average Carbon Intensity	13	40	79	198	1782	307

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

Exhibit 20: Sector Contribution to Active Return of Unconstrained Carbon-Efficient Portfolio (Equal-Weighted)

SECTOR WEIGHTS	BENCHMARK SECTOR WEIGHTS (%)	BENCHMARK CONTRIBUTION TO RETURNS (%)	UNCONSTRAINED CARBON-EFFICIENT PORTFOLIO		
			PORTFOLIO WEIGHT (%)	ACTIVE SECTOR WEIGHTS (%)	PORTFOLIO CONTRIBUTION TO ACTIVE RETURN (%)
Consumer Discretionary	11.31	1.55	10.72	-0.59	0.52
Consumer Staples	10.39	1.07	0.00	-10.39	-
Energy	10.47	0.33	0.00	-10.47	-
Financials	15.90	0.43	61.31	45.41	-0.58
Health Care	13.11	1.37	7.10	-6.01	0.56
Industrials	10.10	0.94	1.97	-8.13	-0.07
Information Technology	19.34	2.55	18.56	-0.78	1.18
Materials	3.28	0.29	0.00	-3.28	-
Real Estate	0.36	0.01	0.29	-0.08	0.02
Telecommunication Services	2.38	0.23	0.05	-2.33	0.01
Utilities	3.34	0.22	0.00	-3.34	-
Unassigned	0.01	0.00	-	-0.01	-
Total	**100**	**8.99**	**100**	**-**	**1.64**

Source: S&P Dow Jones Indices LLC. Data from May 31, 2007, to Dec. 31, 2017. Past performance is no guarantee of future results. Table is provided for illustrative purposes and reflects hypothetical historical performance. Please see the Performance Disclosure at the end of this document for more information regarding the inherent limitations associated with back-tested performance.

S&P DJI RESEARCH CONTRIBUTORS		
Charles Mounts	Global Head	charles.mounts@spglobal.com
Jake Vukelic	Business Manager	jake.vukelic@spglobal.com
GLOBAL RESEARCH & DESIGN		
AMERICAS		
Aye M. Soe, CFA	Americas Head	aye.soe@spglobal.com
Dennis Badlyans	Associate Director	dennis.badlyans@spglobal.com
Phillip Brzenk, CFA	Director	phillip.brzenk@spglobal.com
Smita Chirputkar	Director	smita.chirputkar@spglobal.com
Rachel Du	Senior Analyst	rachel.du@spglobal.com
Bill Hao	Director	wenli.hao@spglobal.com
Qing Li	Director	qing.li@spglobal.com
Berlinda Liu, CFA	Director	berlinda.liu@spglobal.com
Ryan Poirier, FRM	Senior Analyst	ryan.poirier@spglobal.com
Maria Sanchez	Associate Director	maria.sanchez@spglobal.com
Kelly Tang, CFA	Director	kelly.tang@spglobal.com
Peter Tsui	Director	peter.tsui@spglobal.com
Hong Xie, CFA	Director	hong.xie@spglobal.com
APAC		
Priscilla Luk	APAC Head	priscilla.luk@spglobal.com
Utkarsh Agrawal, CFA	Associate Director	utkarsh.agrawal@spglobal.com
Liyu Zeng, CFA	Director	liyu.zeng@spglobal.com
Akash Jain	Associate Director	akash.jain@spglobal.com
EMEA		
Sunjiv Mainie, CFA, CQF	EMEA Head	sunjiv.mainie@spglobal.com
Leonardo Cabrer, PhD	Senior Analyst	leonardo.cabrer@spglobal.com
Andrew Innes	Associate Director	andrew.innes@spglobal.com
INDEX INVESTMENT STRATEGY		
Craig J. Lazzara, CFA	Global Head	craig.lazzara@spglobal.com
Fei Mei Chan	Director	feimei.chan@spglobal.com
Tim Edwards, PhD	Senior Director	tim.edwards@spglobal.com
Anu R. Ganti, CFA	Director	anu.ganti@spglobal.com
Hamish Preston	Senior Associate	hamish.preston@spglobal.com
Howard Silverblatt	Senior Index Analyst	howard.silverblatt@spglobal.com

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