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Decarbonization Factors

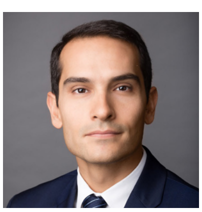
Alexander Cheema-Fox, Bridget Realmuto LaPerla,
George Serafeim, David Turkington, and Hui (Stacie) Wang

Alex Cheema-Fox

Alex Cheema-Fox leads flow and positioning research at State Street Associates (SSA). Since joining SSA in late 2008, Alex has contributed to the construction and application of behavioral measures spanning the fixed-income, equity, factor, and foreign exchange spaces, as well as applied to ESG investing. He has presented this research globally at numerous conferences. Prior to joining SSA, he worked at the RIS Consulting Group, where he built and applied quantitative risk models for customized structured products, serving a variety of institutional clients including asset owners and asset managers. Alex holds a Bachelor's degree in mathematics, a Master's degree in quantitative finance, a Master's degree in computer science, the FRM certification, and the CFA charter.

Bridget Realmuto LaPerla

Bridget is a vice president and Co-Head of ESG Research at State Street Associates. In this role, Bridget develops and promotes industry leading research on environmental, social and, governance themes (ESG). She applies quantitative methods to understand ESG signals in capital markets and leverages insights from State Street's academic partnerships and data. Bridget has published ESG research articles in various industry journals and presents at conferences as an ESG specialist. In addition, Bridget has sat as a voting member of the Advisory Committee on Socially Responsible Investing to the Columbia University Trustees. Prior to joining SSA, Bridget held roles in research and asset management at S&P Global Trucost and Domini Impact Investments, where she designed frameworks to assess ESG performance of equity and fixed income securities. Bridget holds a M.B.A. from Columbia Business School, a B.A. from The George Washington University, and a Certificate in Sustainability Analytics from Columbia University.



George Serafeim

George Serafeim is the Charles M. Williams Professor of Business Administration and the Faculty Chair of the Impact-Weighted Accounts Project at Harvard Business School. He has taught courses in the MBA, executive education, and doctoral programs, and has presented his research in over 60 countries around the world, including to world leaders in government and business at events such as the World Economic Forum at Davos and the Aspen Ideas Festival. He ranks among the top 10 most popular authors out of over 12,000 business authors on the Social Science Research Network.

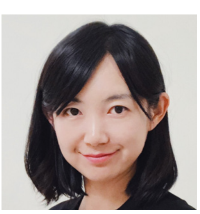
Professor Serafeim's research focuses on measuring, driving and communicating corporate performance and social impact. His work is widely cited and has been published in the most prestigious academic and practitioner journals, such as Management Science, The Accounting Review, Strategic Management Journal, Journal of Accounting and Economics, Journal of Finance, Organization Science, Journal of Accounting Research, and Harvard Business Review. His research is regularly cited in the media, including The New York Times, Bloomberg, Financial Times, The Wall Street Journal, Economist, BBC, Le Monde, Washington Post, and NPR. He has received multiple awards and recognitions, including the Pericles Leadership Award in recognition of services to the Hellenic Republic and the Kim B. Clark Fellowship on Responsible Leadership at Oxford University, the Dr. Richard A. Crowell Memorial Prize, and the Graham and Dodd Scroll Award, for his research on corporate purpose, sustainability and the integration of environmental, social and governance (ESG) issues in business strategy and investing. The elective course "Reimagining Capitalism: Business and Big Problems (pdf)" in the MBA curriculum, which he taught with Professor Rebecca Henderson, received the Ideas Worth Teaching Award from the Aspen Institute and the Grand Page Prize. He has been recognized by Barron's as "one of the most influential people in ESG investing."

Professor Serafeim has held several positions of leadership. He serves on the board of directors of Liberty Mutual, a Fortune 100 company, and AEA-Bridges Impact Corp., the steering committee of the Athens Exchange Group and as the Chairman of Greece's Corporate Governance Council. He co-founded the advisory services firm KKS Advisors and the technology firm Richmond Global Sciences. Moreover, he has extensive experience in the investment management industry. He is an academic partner at State Street Associates and serves on the advisory board of investment firms that focus on ESG issues as catalysts for value creation. He has served on several not-for-profit organizations including the board of directors of the High Meadows Institute and the Standards Council of the Sustainability Accounting Standards Board, and on the first ever decarbonization advisory panel for the New York Common Retirement Fund, one of the largest US pension funds.

Professor Serafeim earned his doctorate in business administration at Harvard Business School, where his dissertation was recognized with the Wyss Award for excellence in doctoral research. He received a master's degree in accounting and finance from the London School of Economics and Political Science, where he was awarded the Emeritus Professors' Prize for best academic performance. He grew up in Athens, Greece.

David Turkington

David Turkington is Senior Managing Director and Head of Portfolio and Risk Research at State Street Associates. His team is responsible for research and advisory spanning asset allocation, risk management and quantitative investment strategy. Mr. Turkington is a frequent presenter at industry conferences, has published research articles in a range of journals, and led the development of State Street's systemic risk and turbulence indicators. He is also co-author of the book A Practitioner's Guide to Asset Allocation. His research has received the 2013 Peter L. Bernstein Award, four Bernstein-Fabozzi/Jacobs-Levy Outstanding Article Awards, and the 2010 Graham and Dodd Scroll Award. Mr. Turkington graduated summa cum laude from Tufts University with a BA in mathematics and quantitative economics, and he holds the CFA designation.



Hui (Stacie) Wang

Hui (Stacie) Wang is the Co-Head of ESG research at State Street Associates. Stacie's ESG research areas of focus thus far have been climate finance, portfolio decarbonization, human capital, and corporate governance in public equity and FX markets. Stacie has over eight years of experience in applying quantitative and machine learning investment models across multiple asset classes. Prior to joining SSA in 2014, she worked in the Enterprise Risk Management group at State Street, where she built quantitative credit risk models for State Street's investment portfolios. Stacie holds a PhD degree in Economics from Ohio State University, a Bachelor's degree in Finance from Shandong Economics University, and is a CFA® charterholder.

Decarbonization Factors

Alexander Cheema-Fox, Bridget Realmuto LaPerla, George Serafeim, David Turkington, and Hui (Stacie) Wang

Alexander Cheema-Fox
is a managing director and head of flow research at State Street Associates in Cambridge, MA.
acheema-fox@statestreet.com

Bridget Realmuto LaPerla
is a vice president and co-head of ESG Research at State Street Associates in Cambridge, MA.
blaperla@statestreet.com

George Serafeim
is Charles M. Williams Professor of Business Administration at Harvard University and an academic partner at State Street Associates in Cambridge, MA.
gserafeim@hbs.edu

David Turkington
is a senior managing director and head of portfolio and risk research at State Street Associates in Cambridge, MA.
dturkington@statestreet.com

Hui (Stacie) Wang
is a vice president and co-head of ESG Research at State Street Associates in Cambridge, MA.
hwang5@statestreet.com

KEY FINDINGS

- The authors develop six strategies to decarbonize a portfolio of US and European-listed equities and find that these decarbonation factors generate positive returns from 2009–2018.
- After controlling for traditional factors, they find that the decarbonization factors that achieve greater carbon reduction also deliver greater alphas.
- They measure institutional flows into and out of the decarbonization factors and find that going with the concurrent flows on low-carbon strategies improves investor returns. This result suggests that institutional flows contain information about climate-related fundamentals.

ABSTRACT

In the face of accelerating climate change, investors are making capital allocations seeking to decarbonize portfolios by reducing the carbon intensity of their holdings. To understand the performance of portfolio decarbonization strategies and investor behavior toward decarbonization, the authors construct decarbonization factors that go long low-carbon-intensity and short high-carbon-intensity sectors, industries, or companies. They consider several portfolio formation strategies and find that strategies that lowered carbon emissions more aggressively performed better. Decarbonization factor returns are associated with contemporaneous institutional flows into the factors. Buying decarbonization factors when coincident flows are positive while selling when they are negative produces significantly positive alphas. Combining decarbonization factors that have positive contemporaneous flows would provide investors with significantly superior returns and continuous exposure to low-carbon portfolios. The results are more pronounced in Europe relative to the United States. The results suggest that institutional investor flows contain information about anticipated fundamentals related to climate change developments.

TOPICS

*ESG investing, portfolio construction, analysis of individual factors/risk premia, performance measurement**

Although climate change is often considered a problem for the future, a growing number of investors are recognizing that risks and opportunities from its systemic shifts are already apparent. The concentration of carbon emissions in 2018 was at its highest level in over 800,000 years, at 413 parts per million, which substantially exceeded all natural fluctuations and the prior high of 300 parts per million, reached over 300,000 years ago (ProOxygen 2019; Lüthi et al. 2008). A preponderance of evidence suggests that this rise is a direct result of human economic activities since the Industrial Revolution.

The increase in carbon emission concentration gives rise to several physical effects, such as sea level rise and droughts, but also to regulatory and technological responses in search of a solution. Assuming warming gets to 2°C, climate change could inflict $69 trillion in damage on the global economy by 2100 (Mufson 2019). More recent estimates from the Intergovernmental Panel on Climate Change (IPCC) forecast a 2°–4°C rise by 2100, thus raising the level of likely economic effects.

Against this backdrop, many investors seek to limit the carbon emissions of the companies in their portfolios (Anderson, Bolton, and Samama 2016; Amel-Zadeh and Serafeim 2018). These portfolio decarbonization strategies take many forms, as one could limit carbon emissions by excluding whole industries or seek to find the companies with the lowest carbon intensity within an industry or sector. Although recent studies have examined pricing and ownership patterns of green bonds (Baker et al. 2018), the pricing of climate risks (Bansal, Kiku, and Ochoa 2016), the reactions by fund managers to disasters (Alok, Kumar, and Wermers 2018), or strategies for hedging climate change news (Engle et al. 2018), our article seeks to document how different decarbonization strategies yield varying results both in terms of risk-adjusted returns and carbon intensity. On the other hand, a recent article by Bolton and Kacperczyk (2020) documents a carbon premium related to the level of carbon emissions—stocks of US companies with higher total carbon emissions earn higher returns; however, no relationship between carbon intensity and stock returns is found after controlling for industry fixed effects.[1] Moreover, given that many investors are now pursuing decarbonization strategies, we are interested in exploring whether institutional flows to decarbonization strategies relate to returns, as investors incorporate information about climate change into their investment processes.

Our data span 2009–2018 for the United States and Europe. We analyze these two geographic segments because they have responded differently to climate change. Admittedly, Europe has responded more aggressively to climate change by instituting a pricing system for carbon emissions (the European Union's emissions trading system [EU ETS]), which provides more-systematic market incentives for businesses to lower their carbon emissions because of stricter carbon regulations and consumers who are generally more sensitive to climate change-related choices. Therefore, we expect investor flows and returns to decarbonization strategies to differ markedly across the two geographies.

We use six distinct portfolio formation decarbonization strategies. The metric we use to classify sectors, industries, or companies into high or low carbon emissions is the sum of Scope 1 and Scope 2 carbon emissions over sales. This metric is well known as carbon intensity and reflects how carbon-efficiently one dollar of revenue is generated. The first three strategies are rotations across sectors or industries. Within them, the first is a sectoral approach whereby we classify sectors according to across-company average carbon intensity. The second and third are industry approaches whereby we classify industries within sectors or within the whole market according to across-company average carbon intensity. The difference between the two is that in the first case an industry that is carbon intensive will be classified as not carbon intensive if it is within a carbon-intensive sector and is less carbon intensive relative to other industries in the sector, while in the second it will be classified as

[1] In contrast to the panel analysis in Bolton and Kacperczyk (2020), our article is at the portfolio level focusing on decarbonization based on operational carbon efficiency using the carbon-intensity measure for companies listed in both US and European markets, and we focus on capitalization-weighted strategies.

carbon intensive. The last three strategies are company-level classifications. They separate companies based on carbon intensity within an industry, a sector, or the market.

We create decarbonization factors for each strategy, buying low-carbon-intensity sectors, industries, or companies and selling high-carbon-intensity equivalents. We then estimate eight-factor models that include controls for the market, size, value, momentum, investment, and profitability factors (Fama and French 2017) and also the oil return and decarbonization flow factors.[2] The analyses suggest that over the period we study, the decarbonization factors delivered a small positive and significant alpha (~2% annually), especially in Europe. The degree of portfolio decarbonization of each strategy differs markedly within market strategies (i.e., not conditioning within sector or industry), thus lowering the carbon intensity significantly more. In addition, we find a positive relationship between the decarbonization alpha from the eight-factor models and how much a portfolio is decarbonized.

Turning our attention to flows, we document a significant contemporaneous positive relationship between decarbonization flows and decarbonization returns. This finding suggests that demand for stocks with low carbon intensity has pricing effects, perhaps because flows of institutional money carry information about changes in the anticipated fundamentals. An alternative explanation is that uninformed demand shocks cause prices to deviate from fundamentals. We do not find evidence of price reversal manifesting as a negative relationship between flows and future returns, which would be consistent with a noise trader story. Moreover, we examine decarbonization factors conditional on flows and find that the factors perform significantly better when flows are positive. Buying the factor when flows are positive, while selling the factor when flows are negative, yields even larger and more significant alphas of between 1.48% and 4.43% in the United States and 2.50% and 8.51% in Europe.

The menu of factors we examine and the relationship between flows and returns allow us to combine factors within and across geographies to create new decarbonization strategies. First, we show that combining decarbonization factors without accounting for flows hardly improves portfolio performance in almost all cases. Second, we find that combining factors with positive flows yields larger significant positive alphas in both the United States and Europe. For example, combining factors with most positive flows across both the United States and Europe creates a decarbonization strategy that delivers a positive and significant alpha of 6.53% annually during the period of our article.

This article contributes to a growing literature on how climate change impacts investor expectations, capital allocations, and thus pricing and returns (Anderson, Bolton, and Samama 2016; Choi, Gao, and Jiang 2019; Alok, Kumar, and Wermers 2019; Engle et al. 2019; Bolton and Kacperczyk 2020). Our results are distinct in several ways. First, we show how different decarbonization portfolio formation strategies yield different returns and carbon characteristics, thereby highlighting that limiting exposure to carbon emissions can be achieved in multiple ways. Second, we shed light on how flows of institutional money to a decarbonization factor relate to decarbonization factor returns, thereby testing the information in institutional investor carbon-related capital allocations. Third, we construct new synthetic decarbonization factors that use information from institutional flows and document the performance improvement over simple decarbonization factors. From a practitioner perspective, our results provide actionable insights into how to decarbonize portfolios and what the likely performance and carbon exposure differences are across strategies.

[2] Removing oil returns from all models leaves all our findings unchanged.

BACKGROUND AND MOTIVATION

Background to Climate Change

The increase in carbon emission concentration has given rise to several physical effects that impact businesses, the economy, and investors' portfolios. It has already led to an increase of 1°C in average global temperature since 1880 and an average sea-level rise of more than 2.6 inches, with the rate of annual increases accelerating (IPCC 2018; National Ocean Service 2019)—a phenomenon that is particularly important given that approximately 3 billion people, about 40% of the world's population, live within 200 kilometers of a coastline (Creel 2003). By 2025, that figure is likely to double, given urbanization trends.

In the Paris Agreement of 2016, countries made voluntary commitments to limit global temperature rise to 2°C. However, the 2014 release of the Fifth IPCC forecasted a 2°C–4°C rise by 2100, and a 2018 special report by the IPCC panel suggested that the commitments under the agreement would likely need to significantly increase given the current trend in carbon emissions (IPCC 2013; IPCC 2018). This trend will have profound effects on sea levels, storm intensity, and water and food availability affecting global agricultural supply chains. Sea levels are expected to rise by 0.52 and 0.98 meters, although more recent projections are calling for as much as a 2-meter rise, displacing hundreds of millions of people globally (IPCC 2013; Bamber et al. 2019). Further, the United Nations Framework Convention on Climate Change (UNFCC) has already linked climate change to increasing land degradation, desertification, and rising hunger, exemplified by severe water shortages in the major metropolitan areas of Cape Town and Chennai (UNFCC 2018). Globally, we are now consuming 1.7 times the annual production of the planet, and it is estimated that if the entire world's population had the same consumption levels as those in the United States, it would take five planets to support it (Global Footprint Network 2019).

Companies are responding to the physical, regulatory, and market changes brought by climate change. Thousands of companies have now set corporatewide carbon-reduction targets through investments in product redesign, real estate modification, renewable energy procurement, and process efficiency (Ioannou, Li, and Serafeim 2016). Moreover, a significant level of disruption is happening in the transportation sector, with the rise of electrified mobility, and in the energy sector, with the rise of renewables—all of which aims to move the economy toward a low-carbon future.

Investor Responses

Against this backdrop, an increasing number of investors are assessing their portfolios against climate-related risks and opportunities. Moreover, new products are being launched to offer options for investors that seek exposure to portfolios with a lower carbon footprint. The New York State Common Retirement Fund allocated $4 billion to a low-emissions index that tilts holdings toward companies with a lower carbon footprint (Krouse 2018). The UNPRI reported a number of institutional investor efforts to decarbonize in their 2018 guide, "How to Invest in the Low-Carbon Economy." The aforementioned portfolio's footprint is 75% lower than that of the Russell 1000 Index. In 2014, the Fourth Swedish National Pension Fund (AP4) announced its intention to decarbonize its equity portfolio by 2020. The New Zealand Superannuation Fund (NZ Super) shifted its global passive equity portfolio (NZ$14 billion) to be managed against a low-carbon benchmark. NZ Super approved a target to reduce its carbon-emission intensity by at least 20% and its carbon-reserve exposure by at least 40% by 2020. The California State Teachers' Retirement System (CalSTRS) committed US$2.5 billion to a low-carbon index invested in US, non-US developed, and emerging equity markets. The passively managed equity portfolio is invested in an index designed to have significantly lower exposure to carbon emissions than the broad market and almost no exposure to fossil fuel reserves. The French Pensions Reserve Fund (FRR) adopted new equity benchmarks to halve its carbon emissions from standard indexes. The fund mandated its passive managers to implement a process to reduce the portfolio's carbon footprint and fossil fuel reserve exposure by 50%. The UK Environment Agency Pension Fund (EAPF) transitioned its portfolio of passively managed global equities to reduce exposure to greenhouse gas emissions by 75%–80% and cut exposure to fossil fuel reserves by 85%–90%.

Portfolio Decarbonization Strategies

Most decarbonization strategies seek to limit the carbon profile of the portfolio by underweighting high-carbon-emission companies and overweighting low-carbon-emission companies. Carbon emissions are measured as the sum of direct and indirect carbon emissions. The former, Scope 1, are the direct carbon emissions generated by the operations of the company and the latter, Scope 2, are the carbon emissions generated by purchased electricity. Scope 3 emissions, which include emissions outside the boundaries of operational control of a company either downstream, generated by product use by the customer, or upstream, generated by a company's supply chain, are not typically considered. This is because only a very small number of companies calculate them, and even within the set of companies that calculate and disclose them, the methodologies tend to vary significantly, impairing the comparability of numbers across companies. Because carbon emissions are greatly influenced by company scale, the most frequently used measure is carbon intensity, whereby carbon emissions are scaled by company sales.

As we describe next, there are many portfolio formation strategies to decarbonize portfolios. Some investors adopt a sectoral or industrial lens whereby they underweight whole sectors or industries while overweighting others. Other investors adopt best-in-class approaches whereby they have exposure to all sectors and industries, but within these, they overweight the lowest-carbon-emission companies while underweighting the highest-carbon-emission companies. These different strategies produce very different carbon profiles.

DATA

Carbon Data

We use security level Scope 1 and Scope 2 carbon-intensity data (hereafter referred to as simply carbon intensity) sourced from Trucost, part of S&P Global. The carbon-intensity metric is calculated as a company's tonnes of carbon emissions emitted per million of USD revenue. Using carbon intensity allows us to compare companies with large operations to those with smaller operations, to assess how efficiently these companies manage carbon emissions for their direct emissions from operations owned or controlled by the company and indirect emissions from generation of energy purchased or acquired for operations (Bhatia and Ranganathan 2004).

We created a daily point-in-time carbon-intensity data universe at the security level mapped to market data and aggregated institutional flows and holdings. The security-level annual carbon-intensity performance data are revised on an ongoing basis throughout the year and from a weekly data feed. This creates multiple "effective" dates for information on an individual security (with overlapping updates by financial year, accounting year, and by weekly files). We identify the most recent update across these and thereby determine carbon intensity at a given trade date. Our factor portfolios are formed on the last business day of June each year.

We identified outliers and removed companies in instances when a company's carbon intensity was greater than five times the trailing maximum value and on the same trading day the company's carbon-intensity-to-market-capitalization ratio was greater than five times the previous trading day's ratio. In those instances, we included the company in the universe if the carbon intensity was smaller than the sector's simple average carbon intensity adding one standard deviation, or if it was within the first 100 trading days of Trucost data coverage.

Price Data

Prices and (free-float) market capitalizations are sourced from Morgan Stanley Capital International (MSCI), taken from the All Country World Investable Market Index (ACWI IMI) universe of securities. Stocks are assigned to countries and regions based on the MSCI classification and to industries and sectors using the global industry classification standard (GICS) system. Returns are computed in USD and are derived from MSCI total return indexes.

With the carbon-intensity and market data, we created six decarbonization factors in each region with different portfolio constructions to track the performance of the decarbonization factors. For instance, for the decarbonization factor that selects companies within an industry, we first allocate companies into low-carbon and high-carbon groups within an industry based on whether the company's carbon intensity is smaller or greater than the industry median. We market-cap weight the companies within the industry and then aggregate across all industries to generate a long portfolio (with low carbon) and a short portfolio (with high carbon). We then take a spread of returns between the long and short portfolio to generate a single market-level series with the security-level data. This aggregation is done at the security level and up to the industry, sector, and market level for the 6 regional strategies, for 12 strategies in total.

$$\mathit{Decarbonization\,Factor\,Returns}_{\mathit{select\ companies\ within\ industry}} = \sum_{i}^{\mathit{all\ industries}} \left\{ \left[\sum_{s \in L(i)}^{\mathit{securities}} \mathit{return}_s \cdot \frac{\mathit{marketCap}_s}{\sum_{s \in L(i)} \mathit{marketCap}_s} - \sum_{s \in H(i)}^{\mathit{securities}} \mathit{return}_s \cdot \frac{\mathit{marketCap}_s}{\sum_{s \in H(i)} \mathit{marketCap}_s} \right] \times \frac{\mathit{marketCap}_i}{\sum_i^{\mathit{all\ industries}} \mathit{marketCap}_i} \right\} \tag{1}$$

where $H(i)$ denotes the set of high-carbon securities in industry I, $L(i)$ denotes low-carbon securities in industry i, and s denotes securities. The market-cap weight of the industry is computed as the industry market capitalization (United States and Europe, respectively) relative to the total regional market capitalization (of the United States and Europe, respectively).

Flow Data

We observe historical daily investment flows from a substantial group of institutional investors represented by anonymized custodial data provided by State Street Corporation.[3] State Street is among the world's largest global custodians, with assets under custody or administration amounting to over $33 trillion as of Q1 2019. These transaction data comprise complete fiduciary accounts of all equity transactions for the portfolios in which these assets are held. In this article, we focus on flows linked to the universe of MSCI securities described in our previous market data section. This dataset has been previously investigated in the context of country equity by Froot, O'Connell, and Seasholes (2001), who found evidence of price impact arising from flows, persistence in flows, and a relation to future returns resulting in part from a combination of the two effects. Within equities, Froot and Teo (2008) extended this line of work to examine flows along factor dimensions and found analogous relationships between flows and returns across a set of common equity factors. We decompose flows into "active" and "benchmark" components at the position level. Benchmark flows are computed each day as net fund flow multiplied by benchmark weights, which are derived from a hedonic regression across funds and securities:

$$\begin{aligned} &log10(\$\ holdings_{fund,security,time}) \\ &\quad = F(fund,\ security, position\ characteristics) + \epsilon_{fund,security,time} \end{aligned} \tag{2}$$

Active flows are computed as the residual flow after subtracting benchmark "expected" flows from observed flows. Active flows are those used in all results in this article. Active flows may be interpreted as capturing intrafund manager-driven rebalance decisions, while benchmark flows may be interpreted as capturing cross-fund investor allocation decisions. Security flow series are derived from summing across funds:

$$flow_{security} = \sum_{funds} flow_{security,fund} \tag{3}$$

Holdings are aggregated across funds analogously; we refer to total holdings (the total position, not the de-benchmarked excess position). When constructing industry-neutral flows across our carbon characteristic, we first compute low- and high-carbon active flows normalized by their respective total holdings (a turnover measure). We then aggregate these within high- and low-carbon groups, weighting normalized flows by the relative market capitalization of the corresponding securities within each of the high and low groups. Then, we compute a spread between these normalized series for each industry (or sector) and finally aggregate these spreads across industries (or sectors) to generate a single market-level series.

$$\begin{aligned} &Decarbonization\ Flows_{select\ companies\ within\ industry} \\ &= \sum_{i}^{\substack{all \\ industries}} \left[\left\{ \left(\sum_{s \in L(i)}^{securities} \frac{flow_s}{holdings_s} \cdot \frac{marketCap_s}{\Sigma_{s \in L(i)} marketCaps_s} \right. \right. \right. \\ &\quad \left. \left. - \sum_{s \in H(i)}^{securities} \frac{flow_s}{holdings_s} \cdot \frac{marketCap_s}{\Sigma_{s \in H(i)} marketCaps_s} \right) \right\} \times \left. \frac{marketCap_i}{\sum_{i}^{all\ industries} marketCap_i} \right] \end{aligned} \tag{4}$$

where *H(i)* denotes the set of high-carbon securities in industry *I*, *L(i)* denotes low-carbon securities in industry *i*, and *s* denotes securities. We define these groups by separating stocks (within a region and market segment with both flow data and carbon characteristic data) into halves. The market-cap weight of the industry is computed as the industry market cap (United States and Europe, respectively) relative to the total regional market capitalization (of the United States and Europe, respectively). This carbon-flow measure is then measured capturing normalized flow spreads between high and low groups. A parallel construction is applied to generate sector-neutral carbon flows.

Data Mapping

We mapped the Trucost security-level carbon-intensity data to MSCI market data using international securities identification numbers (ISINs). For each company, we used an MSCI time-series code as the main identifier, which allows us to keep track of companies historically, even companies that had name and ISIN changes. We then mapped this dataset to State Street's proprietary custodial flow and holding data. We included companies with a market cap of $2 billion, adding and removing those companies when we formed decarbonization portfolios, as companies vacillated above or below the threshold, to minimize outliers. These outliers could potentially be due to imputation issues or reporting errors (Kotsantonis and Serafeim 2019). Most companies below that market-cap threshold do not report carbon-emission data, and therefore their emissions are estimated by input output tables that can generate large forecasting errors. In addition, we removed observations for a company if there was no update for the company's carbon intensity from Trucost for three consecutive years.

Once mapped to the price data and active institutional flows under custody, the carbon-intensity data universe spans June 30, 2009–December 31, 2018. As of the end of the 2018, a total of 2,149 companies and more than USD$34 trillion mid- and large-cap (more than USD$2 billion) listed equities mapped to our active institutional flows data. Among these companies, 1,403 are US-listed companies and 746 are European-listed companies, according to MSCI classifications. Summary statistics of our samples are provided in Exhibit 1. Our sample includes US and European companies that in 2018 released 2 billion and 2.2 billion carbon emissions, respectively. This sample is ecologically meaningful, as the carbon emissions from fossil fuel combustion, cement manufacturing, and gas flaring were 5.3 billion and 3.5 billion for the United States and Europe, respectively.[4]

Multifactor Model Estimation

We form long-short portfolios on the last trading day of June from 2009–2018 and hold the portfolios for one year. In each region, we have three select company decarbonization portfolios, two select industry portfolios, and one select sector portfolio. For the select companies within the industry portfolio, companies within each industry are allocated into two groups—low-carbon risk (the long side) and high-carbon risk (the short side)—depending on whether the company's point-in-time carbon intensity is below or above the industry median at the end of June of each year. We construct the long–short portfolio to be industry neutral, such that the long and short side have the same portfolio weight for each industry, which equals the industry's market-cap weight. The select companies within the sector portfolio are sector neutral and constructed in a similar fashion, while select companies within the market portfolio have no constraint and the sorting is across all sectors and industries. The two select industry portfolios and one select sector portfolio are built in the same way, except that the underlying data are at the industry or sector level instead of at the company level.

Once a portfolio is formed, there is no rebalancing between portfolio formation dates. On rare occasions when a company's stock is delisted, an industry is discontinued, or a company's carbon-intensity data cannot be matched with its market data after the current rebalance date but before the next rebalance date, capital invested in the stock or industry is reallocated to other stocks or industries based on the portfolio weights.

To formally test the performance of the 12 decarbonization factor portfolios, 6 for the United States and 6 for Europe, we set up a time-series multifactor framework whereby we regress the decarbonization factor returns on the Fama–French

EXHIBIT 1
Investable Universe: Summary Statistics

Year	Number of Unique Companies	Total Market Cap (billion$)	Market-Cap-Weighted carbon Intensity (tonnes carbon emissions/mil$)	Total Carbon Emissions (tonnes carbon emissions)
Panel A: United States				
2009	529	3,568	123.9	842,934,237
2010	645	7,536	181.2	1,453,950,612
2011	674	9,044	176.6	1,495,329,874
2012	669	9,764	171.3	1,283,775,059
2013	685	11,598	160.7	902,098,268
2014	736	14,433	152.9	1,094,526,192
2015	801	16,349	130.3	1,570,509,812
2016	832	16,473	154.8	1,892,928,027
2017	1208	20,041	157.3	1,780,299,525
2018	1403	25,189	163.2	1,998,380,662
Panel B: Europe				
2009	336	2,228	138.0	658,724,076
2010	381	4,035	204.4	1,195,025,393
2011	412	4,481	193.2	1,190,195,971
2012	396	4,157	155.3	1,153,121,756
2013	453	5,175	110.6	1,187,855,024
2014	509	6,253	107.5	1,280,790,306
2015	535	6,561	113.5	1,454,364,192
2016	557	6,387	122.4	1,813,901,441
2017	650	8,002	122.6	1,996,748,721
2018	746	9,190	152.0	2,229,775,106

NOTES: The panels present summary statistics of our samples for the US and European market from July 2009–December 2018. This exhibit reflects a universe of securities with daily timestamped carbon, fundamental, flow, and holding data with a market cap at or over $2 billion. Details on the sample selection process are described in the data section of the article.

five factors (market, size, value, profitability, and investment), the momentum factor, NYMEX oil spot returns, as well as the corresponding portfolio's decarbonization flows, as follows:[5]

$$\begin{aligned}&Decarbonization\ Factor\ Returns_t\\&\quad = \alpha + \beta_1(R_{Mt} - R_{Ft}) + \beta_2 SMB_t + \beta_3 HML_t + \beta_4 RMW_t + \beta_5 CMA_t\\&\qquad + \beta_6 WML_t + \beta_7 Oil_t + \beta_8 Decarbonization\ Flows_t + \varepsilon_t\end{aligned} \tag{5}$$

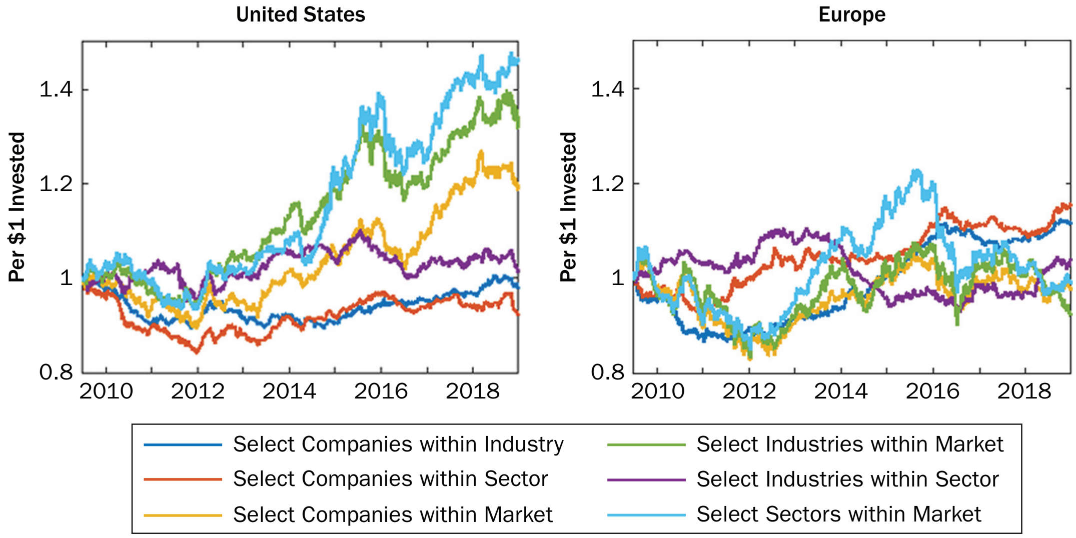
As described in the earlier in the Flow Data section, we engineered the decarbonization flows to reflect the real-money buying and selling across high- and low-carbon groups at the company, industry, or sector level based on State Street's institutional investor flow and holding data. Like the 6 decarbonization factors in each region, we have 6 corresponding decarbonization flows based on their respective portfolio constructions. Note that the flows in each regression are the flows from the corresponding decarbonization portfolio.

Our estimation model examines the correlation between carbon risk and changes in stock prices at company, industry, or sector levels for a given portfolio specifica-

[5] FF5 factors and momentum factor data are from Kenneth French's online data library, available at https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html. We used US FF5 and momentum factors for US portfolios and European FF5 and momentum factors for European portfolios.

EXHIBIT 2

Cumulative Returns for Decarbonization Factors



NOTES: Exhibit 2 presents cumulative performance for a $1 investment in the decarbonization factors from July 1, 2009–December 31, 2018. All decarbonization factors are constructed from long–short portfolios that are formed on the last trading day of June each year, with a holding period of one year. For the select companies within the industry portfolio, companies within each industry are allocated into two groups—low-carbon risk (the long side) and high-carbon risk (the short side)—depending on whether the company's carbon intensity is below or above the industry median. The portfolio is constructed to be industry neutral, such that the long and short side have the same portfolio weight for each industry, which equals the industry's market-cap weight. The select companies within the sector portfolio are sector neutral and constructed in a similar fashion, while select companies within the market portfolio have no constraint and the sorting is across all sectors and industries. The two select industry portfolios and one select sector portfolio are built in the same way, except that the underlying data are at the industry or sector level instead of the company level.

tion. Alpha captures the performance that cannot be explained by the traditional risk factors, as well as changes in oil prices and institutional investor flows. By including the decarbonization flows in the estimation, we can investigate the relationship between the flows and decarbonization factors, or how the decarbonization factors' performance aligns with investors' decarbonization behavior for the first time in the literature. The model also controls for oil returns, because some industries or sectors, such as energy and transportation, are subject to energy price cycles, which could confound the decarbonization factor performance. All estimations are based on monthly return data with no overlapping periods from July 2009–December 2018. Heteroskedasticity and autocorrelation-consistent standard errors are used to compute the *t*-statistics and level of significance.

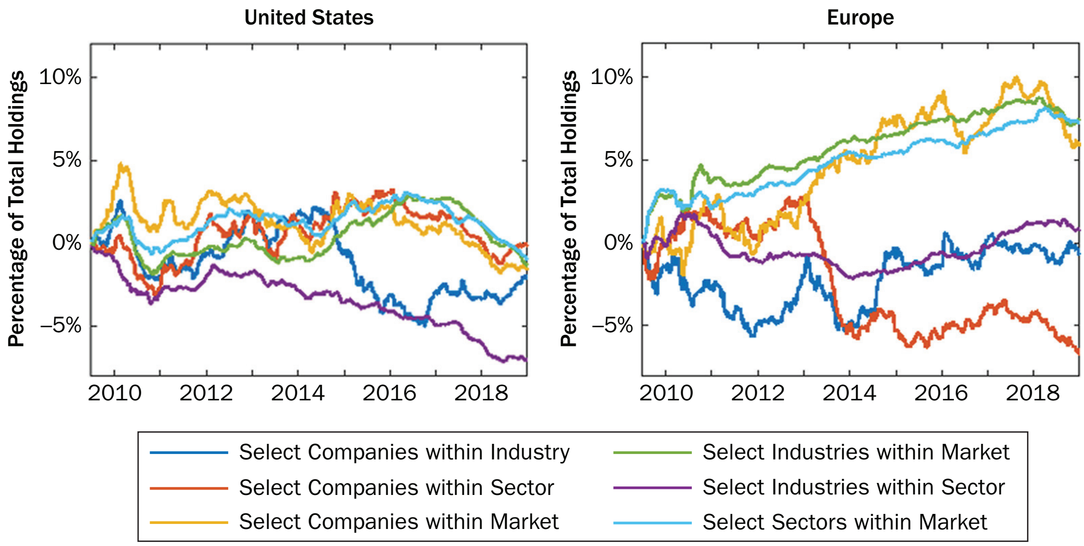
RESULTS

Performance of Decarbonization Factors

Exhibit 2 shows the cumulative performance of the different decarbonization factors. A few things are noteworthy. Almost all of them (except for select industries within sectors in Europe) perform poorly between 2009 and 2012. After that period, the performance picks up. The performance of the select industries and select companies within market decarbonization factors in the United States is remarkably strong. In Europe, select companies within industry or within sector factors are also strong.

EXHIBIT 3

Cumulative Institutional Money Flows for Decarbonization Factors



NOTES: Exhibit 3 presents cumulative decarbonization flows that correspond to the decarbonization factors from July 1, 2009–December 31, 2018. The vertical axis is in percentage of total holdings. The different portfolio formation strategies for the decarbonization factor are described in the text.

Exhibit 3 demonstrates the daily active investor flows for each decarbonization factor and illuminates a striking difference for flows in Europe and the United States. In Europe, real-money moved into the decarbonization factors that were the most aggressive in lowering carbon emissions, specifically the three within market strategies. Alternatively, while those same strategies generally saw inflows between 2014 and 2016, there is a decline in the United States after the 2016 change in the presidential administration.

In Exhibit 4, we observe economically and statistically significant positive alpha for select companies within sector and market factors in Europe. The decarbonization factors exhibit a strong negative relation to the profitability factor and in three cases to the oil factor. Both relations are stronger for decarbonization factors that select companies within the market factor, suggesting that imposing sector or industry constraints produces portfolios that are less correlated with other factors.

The alphas for the US select industries and select sectors within the market factors are marginally significant at the 10% level. The decarbonization factors exhibit strong negative correlation with the investment factor and the profitability factor. As in the case of Europe, these results are more pronounced for the within-market portfolios, which also exhibit a negative relation to the size factor and a positive relation to the market factor. Exhibit 5 plots the cumulative abnormal returns for all different strategies.

All decarbonization factors, both in Europe and the United States, exhibit a positive relation with the flow factor. In 9 of the 12 factors, this relationship is statistically significant. Flows seem to be associated with more positive returns on the decarbonization factor.

Another observation from these decarbonization portfolios is that their performance does vary over time during our sample period from 2009–2018. We notice that these strategies have better risk-adjusted performance since 2012 compared with 2009–2011, which can be seen through the cumulative abnormal performance shown in Exhibit 5. With additional analysis, we find that 10 of the 12 factors have greater

EXHIBIT 4

Regression on Decarbonization Factor Returns

	Select Companies within Industry		Select Companies within Sector		Select Companies within Market		Select Industries within Sector		Select Industries within Market		Select Sectors within Market	
Variables	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat
Panel A: United States												
Alpha	0.25%	0.27	–0.95%	–0.76	1.89%	1.57	0.72%	0.51	2.52%	1.76	3.01%	1.96
Market	–0.03	–1.02	0.03	0.93	0.11	2.51	0.06	1.52	0.13	3.09	0.16	3.66
SMB	0.03	0.82	–0.06	–1.41	–0.15	–3.07	0.00	0.08	–0.15	–2.55	–0.18	–2.81
HML	0.03	0.64	–0.01	–0.20	0.30	4.86	0.07	1.15	0.14	1.84	0.11	1.37
RMW	0.06	1.11	–0.02	–0.34	–0.23	–3.35	–0.01	–0.17	–0.31	–4.30	–0.29	–3.42
CMA	–0.10	–2.11	–0.15	–2.39	–0.68	–6.41	–0.24	–2.55	–0.57	–4.32	–0.55	–3.81
WML	0.01	0.47	–0.02	–0.67	–0.01	–0.25	–0.06	–1.52	0.05	1.21	0.07	1.49
Oil	0.00	–0.09	0.03	1.45	–0.02	–1.05	0.04	3.22	–0.04	–2.15	–0.11	–5.39
Decarbonization Flows	0.39	2.17	0.81	3.87	0.49	1.77	1.05	2.34	0.55	1.10	1.06	1.64
Panel B: Europe												
Alpha	0.83%	0.63	2.34%	2.49	3.91%	3.73	2.40%	1.77	2.82%	1.49	2.38%	1.50
Market	0.00	0.01	–0.02	–0.75	0.01	0.29	–0.05	–1.93	0.08	2.33	0.05	1.38
SMB	0.16	2.65	–0.02	–0.29	–0.10	–1.54	–0.12	–2.28	–0.12	–1.32	–0.11	–1.30
HML	–0.09	–1.42	–0.26	–2.91	–0.09	–1.15	–0.24	–2.33	–0.19	–1.68	–0.11	–0.94
RMW	0.02	0.17	–0.08	–0.90	–0.82	–7.08	–0.35	–2.99	–1.15	–6.83	–0.97	–5.75
CMA	0.14	1.63	0.05	0.48	–0.23	–1.66	0.01	0.06	–0.40	–2.10	–0.29	–1.14
WML	0.00	–0.01	–0.03	–0.88	–0.03	–0.61	–0.01	–0.36	0.03	0.39	0.05	0.77
Oil	–0.01	–1.47	0.01	0.58	–0.07	–5.01	0.02	1.78	–0.07	–4.52	–0.11	–7.90
Decarbonization Flows	0.64	3.68	0.24	1.64	0.56	2.73	1.37	2.86	1.74	3.46	2.19	3.08

NOTES: Exhibit 4 presents estimates and *t*-statistics from nonoverlapping monthly calendar regressions of decarbonization factor returns on the eight factors tabulated, the Fama–French 5 factors (market, size, value, profitability, and investments), momentum, the NYMEX oil spot returns, and our defined decarbonization flows. Alphas are annualized. The different portfolio formation strategies for the decarbonization factor are described in the text.

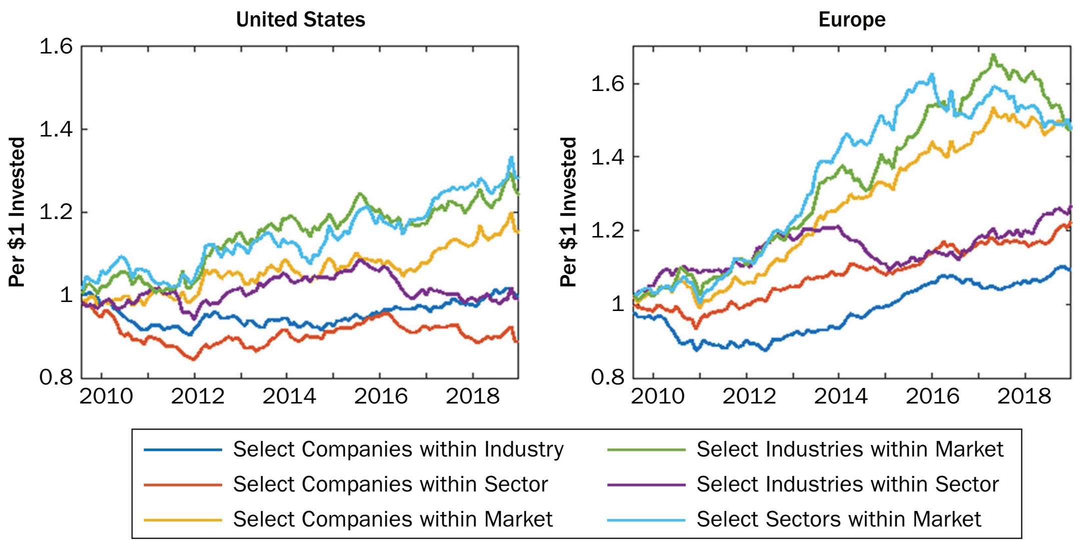
returns since 2012. This phenomenon is especially noticeable for the US portfolios, which lag behind the European portfolios but catch up in recent years. All US factors have negative or close to zero returns in 2009–2011 but turn positive thereafter.[6]

Correlation of Decarbonization Factor Returns across Strategies. Exhibit 6 shows univariate correlations among decarbonization factor returns across all strategies. We are interested in the portfolio formation strategy cross-correlations to understand the opportunities for investors to employ multiple decarbonization strategies simultaneously, thereby improving portfolio performance. Panel A shows that select companies within industry or sector exhibit stronger correlation with select industries or sectors in the United States compared with Europe. The lower cross-correlations in Europe suggest that investors not only have more opportunities for diversification in Europe, but also that the choice of the decarbonization strategy produces a wider spectrum of results. Between the United States and Europe, only the select companies within

[6] This change in the trend of the decarbonization factors corresponds to the 17th session of the Conference of the Parties (COP 17) to the UNFCCC and the 7th session of the Conference of the Parties serving as the meeting of the Parties (CMP 7) to the Kyoto Protocol in November–December 2011. During the meetings, participants agreed on a legally binding agreement to address global warming. This agreement was a significant step forward; for the first time, it included the United States (which used to refuse to join the Kyoto Protocol) as well as developing countries such as China and India.

EXHIBIT 5

Cumulative Abnormal Returns for Decarbonization Factors



NOTES: Exhibit 5 presents cumulative abnormal returns for a $1 investment in the decarbonization factors from July 1, 2009–December 31, 2018. The abnormal returns are estimated from regressions based on nonoverlapping monthly data, controlling for market, size, value, profitability, investment, and momentum factors and returns of the NYMEX oil spot.

market, select industries within market, and select sectors within market are highly correlated. This also suggests opportunities for diversification across strategies.

Portfolio Decarbonization

We calculate for each strategy its portfolio decarbonization (PD), measured as the market-cap-weighted carbon intensity of the short portfolio minus the market-cap-weighted carbon intensity of the long portfolio, divided by the market-cap-weighted carbon intensity of the overall market. We calculate this ratio for each day and tabulate the average PD across all days in the sample.

$$PD = \frac{carbon\ intensity_{portfolio,Short} - carbon\ intensity_{portfolio,Long}}{carbon\ intensity_{market}} \tag{6}$$

The strategies exhibit very different PD. The more we constrain our portfolio construction, the less we decarbonize the portfolio. For example, select securities within market have a higher PD compared with select securities within sector; select securities within sector have a higher PD compared with select securities within industry. The results can be seen in Exhibit 7. In the United States, for the select company portfolios within market, sector, and industry, the PD is 2.07, 1.41, and 1.15, respectively. The PD for the select industries within sector, select industries within market, and select sectors within market is 1.36, 2.84, and 3.35, respectively. In Europe, the PD for the portfolios that select companies within market, sector, and industry is 2.00, 1.25, and 1.07, respectively. The PD for the select industries within sector, select industries within market, and select sectors within market is 0.97, 2.08, and 2.07, respectively.

$$PD = \frac{carbon\ intensity_{portfolio,Short} - carbon\ intensity_{portfolio,Long}}{carbon\ intensity_{market}}$$

EXHIBIT 6

Correlation of Decarbonization Factor Returns across Strategies

Panel A: United States

Strategies		(1)	(2)	(3)	(4)	(5)
Select Companies within Industry	(1)	1.00				
Select Companies within Sector	(2)	0.51**	1.00			
Select Companies within Market	(3)	0.27**	0.52**	1.00		
Select Industries within Sector	(4)	0.17*	0.64**	0.43**	1.00	
Select Industries within Market	(5)	0.11	0.31**	0.82**	0.28**	1.00
Select Sectors within Market	(6)	0.11	0.17*	0.63**	0.08	0.80**

Panel B: Europe

Strategies		(1)	(2)	(3)	(4)	(5)
Select Companies within Industry	(1)	1.00				
Select Companies within Sector	(2)	0.57**	1.00			
Select Companies within Market	(3)	0.06	0.05	1.00		
Select Industries within Sector	(4)	–0.05	0.30**	0.15	1.00	
Select Industries within Market	(5)	–0.12	–0.08	0.86**	0.20**	1.00
Select Sectors within Market	(6)	–0.03	–0.12	0.89**	0.08	0.83**

Panel C: United States and Europe

			Europe Decarbonization Factors					
	Strategies		(1)	(2)	(3)	(4)	(5)	(6)
US Decarbonization Factors	Select Companies within Industry	(1)	0.15*	0.16**	0.07	–0.14**	0.08	0.06
	Select Companies within Sector	(2)	0.22*	0.21**	–0.04	–0.03	–0.03**	–0.01
	Select Companies within Market	(3)	0.01	0.10	0.44**	0.17*	0.47**	0.42**
	Select Industries within Sector	(4)	0.21	0.14	0.18*	0.00	0.19**	0.10
	Select Industries within Market	(5)	0.05	0.19	0.46**	0.31**	0.46**	0.40**
	Select Sectors within Market	(6)	0.00	0.02	0.36**	0.09	0.48**	0.48**

NOTES: Exhibit 6 Panel A (B) presents univariate correlations among returns to the US (European) decarbonization factors constructed using different strategies. Panel C presents univariate correlations among decarbonization factor returns in the United States and in Europe. The decarbonization factor goes long on low-carbon-intensity sectors, industries, or companies and short on high-carbon-intensity sectors, industries, or companies. ** and * indicate significance at the 5% and 10% levels, respectively.

EXHIBIT 7

Portfolio Decarbonization Statistics

Region	Select Companies within Industry	Select Companies within Sector	Select Companies within Market	Select Industries within Sector	Select Industries within Market	Select Sectors within Market
United States	1.15	1.41	2.07	1.36	2.84	3.35
Europe	1.07	1.25	2.00	0.97	2.08	2.07

NOTES: In Exhibit 7, we calculate the PD for each strategy. PD is measured as the market-cap-weighted carbon intensity of the short portfolio minus the market-cap-weighted carbon intensity of the long portfolio, divided by the market-cap-weighted carbon intensity of the overall market. We calculate this ratio for each day and tabulate the average PD across all days in the sample.

A few more observations are worth noting. Moving from select companies within market to select companies within sector significantly decreases the carbon intensity of the short portfolio relative to the market portfolio from 218% to 167%, while moving from select sectors to select industries has a much less meaningful effect (167% to 162%), as shown in Exhibit 8. In contrast, moving from select sectors to industries has a much more meaningful effect on the long portfolio increasing its carbon intensity relative to the market portfolio from 26% to 47%. A similar pattern exists in Europe. This means that moving from a sector to an industry best-in class portfolio formation has little carbon effect on the short portfolio but a much larger carbon effect on the long portfolio. Therefore, an investor that wants to hold all industries in the long portfolio will bear a significant carbon penalty.

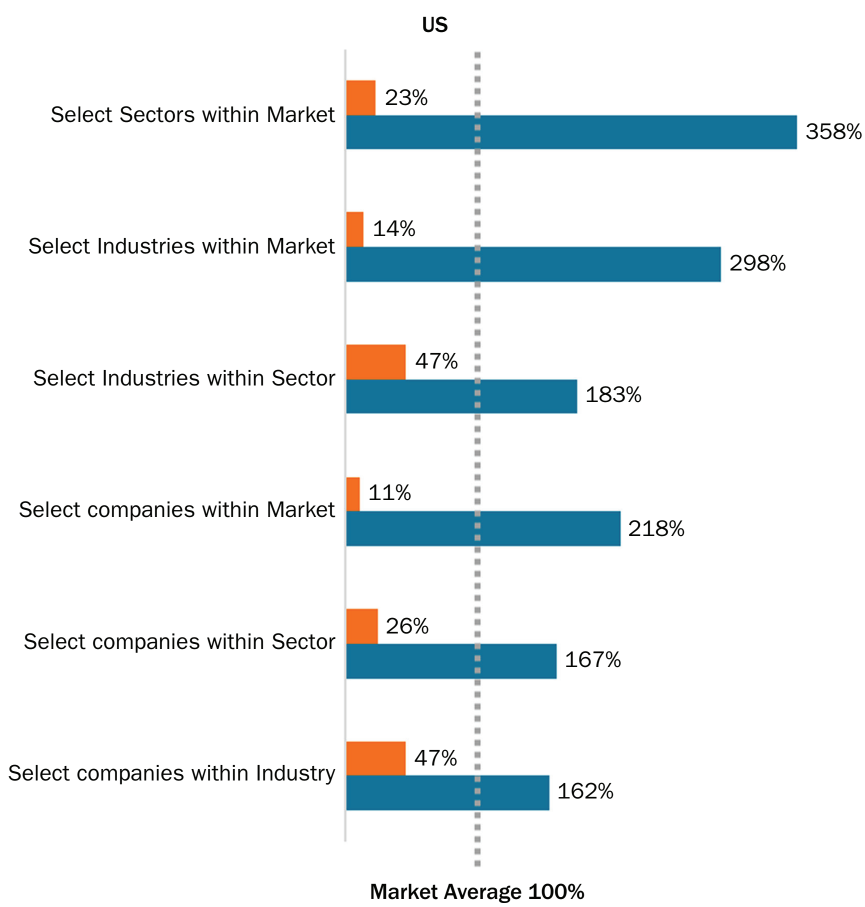
Decarbonization and Alpha

For each of the portfolio strategies, we measured their alphas from the multi-factor model relative to how much they lower carbon emissions. We plot the results for all portfolios in Exhibit 9. In the horizontal axis is the alpha, and in the vertical axis is the PD. If investors seek to limit their carbon exposure while seeking alpha, then portfolios in the upper right corner are more appealing. For both Europe and the United States, there seems to be a positive relation between PD and decarbonization alpha across strategies.

We also calculate how much our portfolio strategies reduce the total carbon emissions, or carbon footprint. In order to differentiate this measure from PD, we

EXHIBIT 8

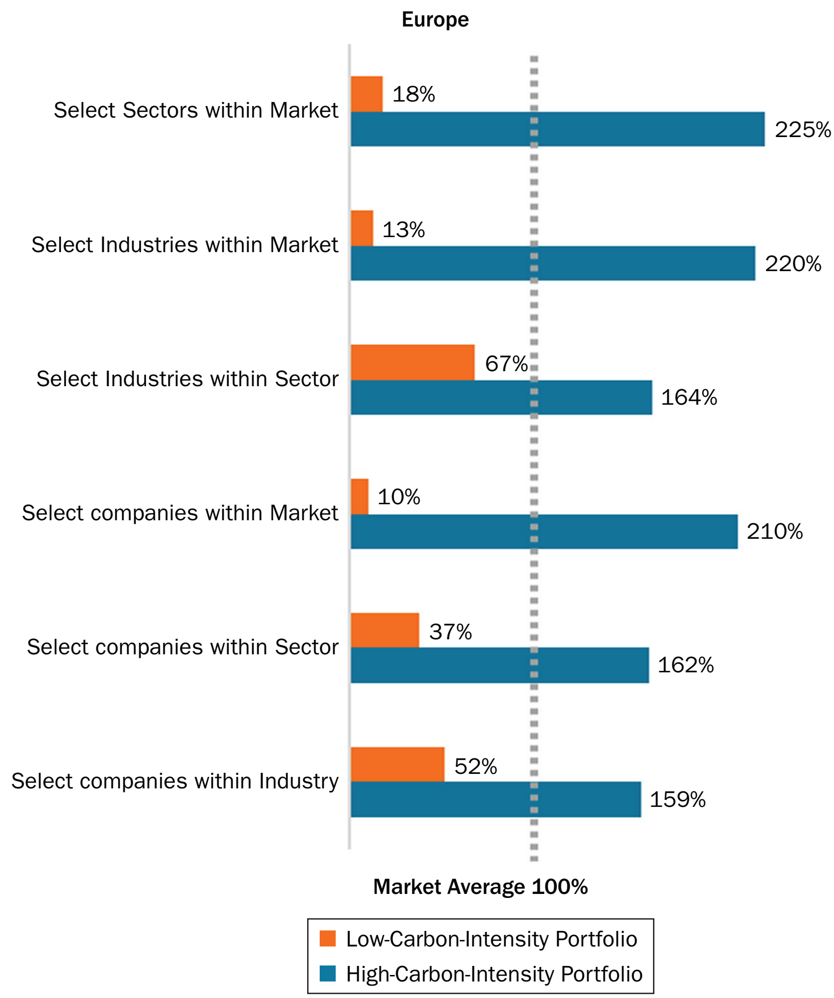
Portfolio Carbon Intensity to Market Average Carbon Intensity Ratio



(continued)

EXHIBIT 8 *(continued)*

Portfolio Carbon Intensity to Market Average Carbon Intensity Ratio



NOTES: Exhibit 8 presents ratios of the market-cap-weighted carbon intensity of the low-carbon portfolio (long portfolio) and high-carbon portfolio (short portfolio), relative to the market-cap-weighted carbon intensity of the market portfolio. These ratios are calculated daily from July 1, 2009–December 31, 2018, and the average ratios are presented in the exhibit.

name it carbon footprint reduction.[7] Exhibit 10 shows the carbon footprint reduction versus decarbonization alpha. Similar to our observations of PD, portfolio strategies that have higher carbon footprint reduction are associated with higher decarbonization alphas for both the United States and Europe.

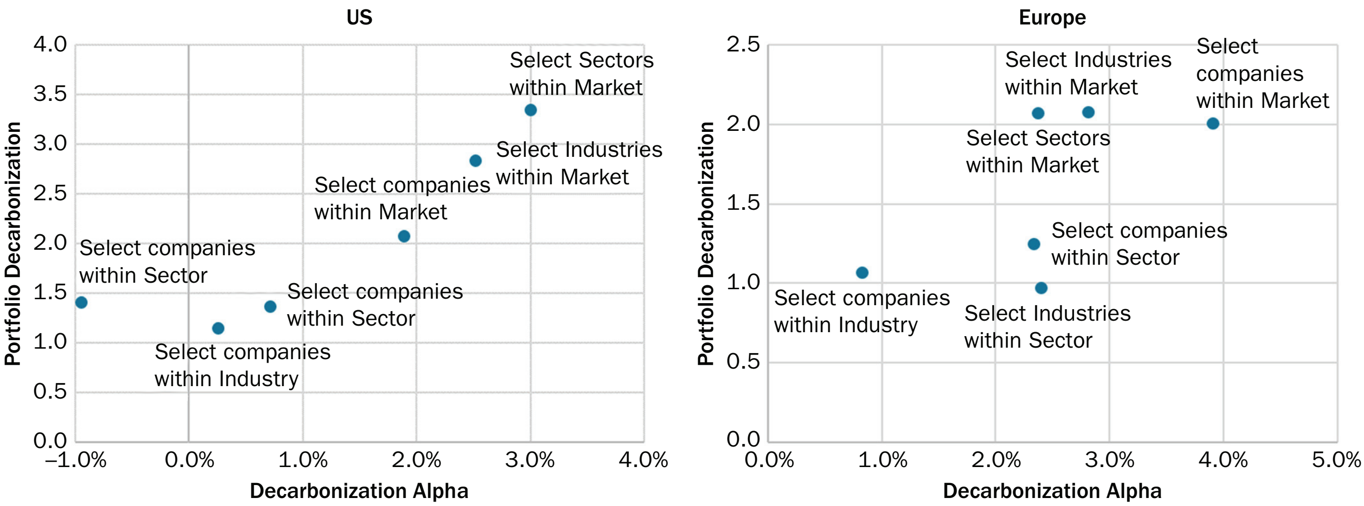
Thus far, we have demonstrated different decarbonization strategies based on alterative schemes. Each of the six decarbonization factors has different constructions and constraints, and each achieves different amounts of carbon reduction. Therefore, we do not expect them to have the same performance. Additionally, we expect different regions to behave differently; Europe was leading the United States in terms of climate regulations and thus investors there had stronger incentives to

[7] The carbon footprint reduction is calculated per strategy as the low-carbon-emission securities (or industries or sectors) from the high-carbon-emission securities (or industries or sectors), divided by the carbon emissions of the market, to capture the amount of carbon reduction.

$$\text{carbon footprint reduction} = \frac{\text{carbon emission}_{\text{portfolio,Short}} - \text{carbon emission}_{\text{portfolio,Long}}}{\text{carbon emission}_{\text{market}}}.$$

EXHIBIT 9

Portfolio Decarbonization and Decarbonization Alpha

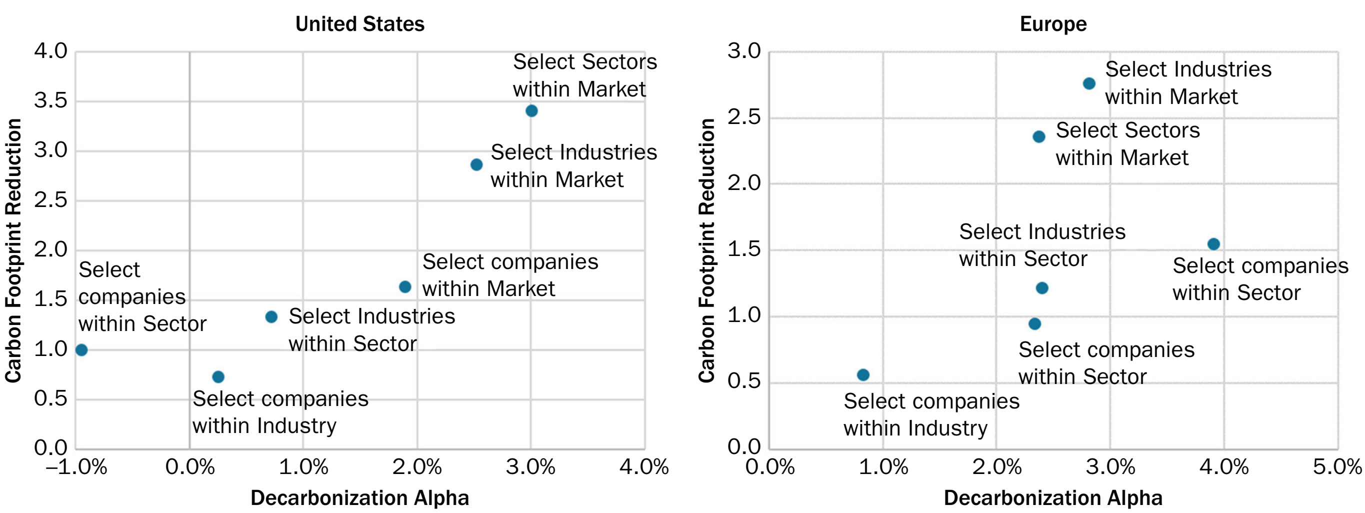


NOTES: Exhibit 9 presents portfolio decarbonization versus decarbonization alpha for the six portfolios in each region. For each strategy, we calculate the PD measured as the market-cap-weighted carbon intensity of the short portfolio (higher-carbon-intensity group) minus the market-cap-weighted carbon intensity of the long portfolio (lower-carbon-intensity group), divided by the market-cap-weighted carbon intensity of the overall market. We calculate this ratio for each day and tabulate the average PD across all days in the sample.

$$PD = \frac{carbon\ intensity_{portfolio,Short} - carbon\ intensity_{portfolio,Long}}{carbon\ intensity_{market}}$$

EXHIBIT 10

Portfolio Carbon Footprint Reduction and Decarbonization Alpha



NOTES: Exhibits 9 and 10 present portfolio carbon footprint reduction versus decarbonization alpha for the six portfolios in each region. The carbon footprint reduction is calculated per strategy as the low-carbon-emission securities (or industries or sectors) from the high-carbon-emission securities (or industries or sectors), divided by the carbon emissions of the market, to capture the amount of carbon reduction.

$$carbon\ footprint\ reduction = \frac{carbon\ emission_{portfolio,Short} - carbon\ emission_{portfolio,Long}}{carbon\ emission_{market}}$$

invest in low-carbon strategies. We think it is informative for investors to see a manual of decarbonization solutions and how these portfolios might look and perform under each construction for both the United States and Europe. This permits investors with different preferences or constraints to understand how decarbonization may impact their portfolios. The way we are unifying our results across the different factors is through the findings that 1) out of the 12 factors, 11 have positive excess returns (as shown in Exhibit 4), indicating that decarbonization factors could, on average, deliver positive performance, and 2) a positive relationship exists between portfolio decarbonization and performance, because the strategies that have greater carbon reduction also deliver greater risk-adjusted returns, as discussed in this section.

Decarbonization Factor Flows in Decarbonization Strategies

We examine the economic significance of flows by separating the factor into two factors based on whether contemporaneous flows are positive or negative. Exhibit 11 shows that across almost all strategies separating the factor according to flows produces different results. A decarbonization factor with positive flows outperforms the decarbonization factor with negative flows across all strategies, except for select industries within market in the United States. For example, in the United States, for the select companies within market portfolio, the decarbonization factor with positive flows grows to $1.30 by the end of 2018, while the decarbonization factor with negative flows declines to $0.92. The respective numbers in Europe are $1.19 and $0.83.

Exhibit 12 shows alphas and *t*-statistics for the alphas from multifactor models of a factor that goes long the decarbonization factor when contemporaneous flows are positive and short when flows are negative. We observe a positive spread across positive and negative flow decarbonization factors across all strategies, ranging from 1.48% for US select industries within market to 8.51% for Europe select sectors within market. Separating the two strategies, we find that the positive flow decarbonization factor consistently delivers positive alphas, which are significant for most strategies except for the US select sector and industry strategies. In contrast, the negative flow decarbonization factor delivers negative alphas in most of the strategies; however, the alphas are significant only in the case of US select companies within sector. This suggests that the alphas in Exhibit 12 are mostly driven by longing the decarbonization factors when flows are positive rather than shorting the factor when flows are negative.

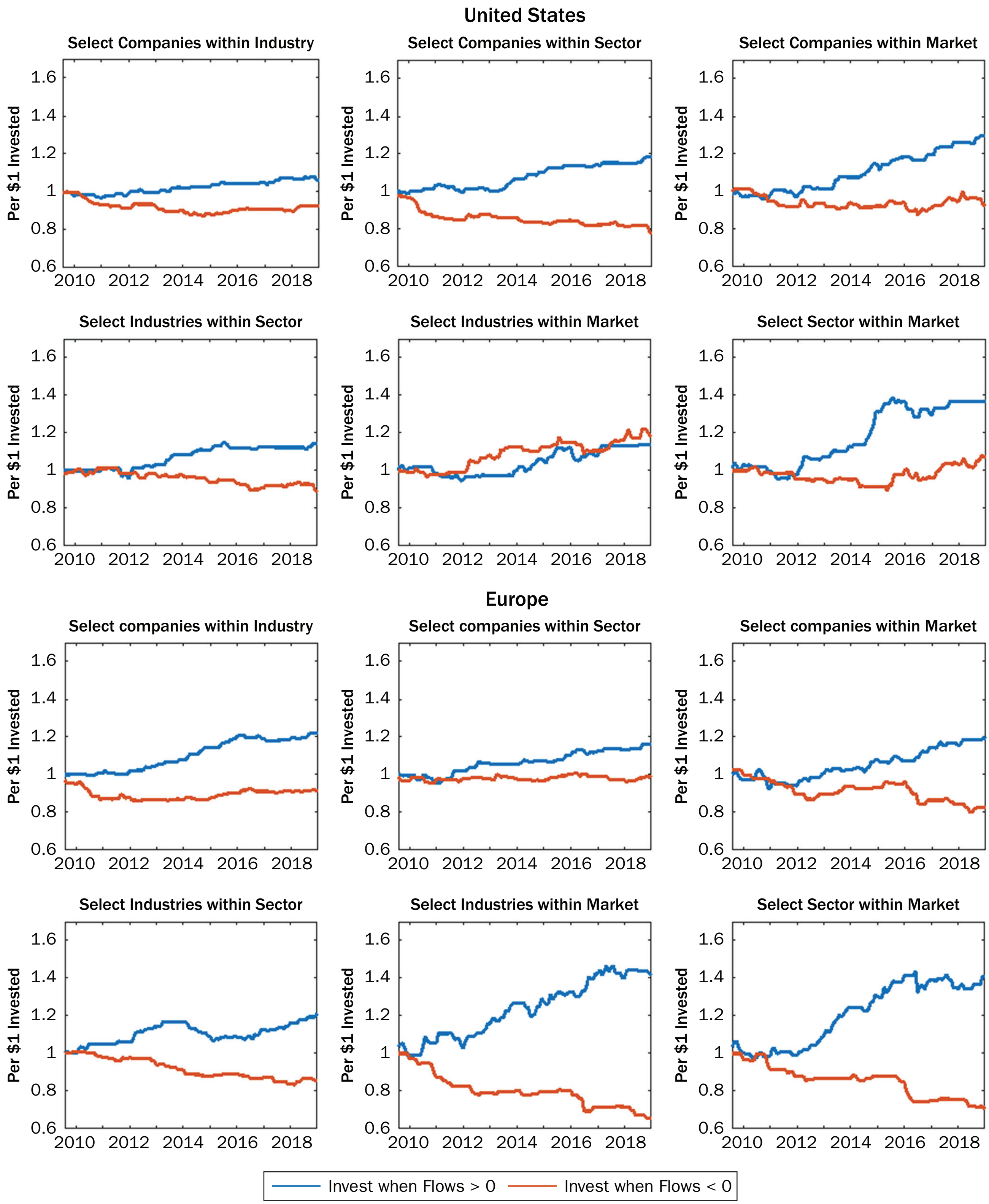
Correlation of decarbonization factor flows across strategies. Exhibit 13 shows univariate correlations among decarbonization factor flows across all strategies. Panel A shows results for the United States; Panel B, for Europe; and Panel C, between the United States and Europe. For most strategy pairs, we find a significantly stronger positive correlation in the United States rather than in Europe. In fact, flows for the best-in-class approaches, select companies within industry or sector, are negatively correlated with the sectoral and industrial rotations in select industries or sectors within market for Europe. Institutional flows seem to exhibit a substitutive effect between allocating capital across industries or sectors, and company selection within industry or sector. Flows across the two geographic regions exhibit very low correlation when using the same strategy.

Price Pressure?

The positive relationship between flows and returns could be the result of institutional flows containing information about changes in fundamentals or of price pressure in the presence of uninformed demand shocks (Froot and Teo 2008). To test the price pressure hypothesis, we regress decarbonization factor returns on lagged flows while controlling for contemporaneous flows. If the lagged flows are negatively

EXHIBIT 11

Cumulative Performance for Decarbonization Factors Conditional on the Sign of Decarbonization Flows



NOTES: Exhibit 11 represents the cumulative performance for a $1 investment in the decarbonization factors conditional on the sign of the flows in the United States and Europe. For each decarbonization factor, we create two portfolios (blue and red in the graphs). One portfolio (blue) invests in the factor when flows are positive and in cash with zero returns when flows are negative. The other portfolio (red) invests in the factor when flows are negative and in cash with zero returns when flows are positive.

EXHIBIT 12

Decarbonization Factor Performance Conditional on Flows

Region	Select Companies within Industry	Select Companies within Sector	Select Companies within Market	Select Industries within Sector	Select Industries within Market	Select Sectors within Market
United States						
Alpha	2.03%	4.43%	3.29%	2.85%	1.48%	2.05%
t-Stat	2.13	3.25	2.16	2.39	0.90	0.90
Europe						
Alpha	2.50%	2.62%	5.12%	4.16%	8.22%	8.51%
t-Stat	2.15	2.06	2.90	3.25	3.71	3.73

NOTES: Exhibit 12 presents estimates of alpha from calendar time regressions of a factor that goes long on the decarbonization factor in months with positive decarbonization flows and short on the decarbonization factors in months with negative flows. Alphas are annualized. Regressions use nonoverlapping monthly data from July 2009–December 2018. The models control for all other factors (as in Exhibit 4), except for decarbonization flows.

EXHIBIT 13

Correlation of Decarbonization Factor Flows across Strategies

Panel A: United States

Strategies		(1)	(2)	(3)	(4)	(5)
Select Companies within Industry	(1)	1.00				
Select Companies within Sector	(2)	0.54**	1.00			
Select Companies within Market	(3)	0.47**	0.65**	1.00		
Select Industries within Sector	(4)	0.16*	0.47**	0.20**	1.00	
Select Industries within Market	(5)	0.21**	0.35**	0.56**	0.28**	1.00
Select Sectors within Market	(6)	0.04	0.11	0.44**	–0.01	0.66**

Panel B: Europe

Strategies		(1)	(2)	(3)	(4)	(5)
Select Companies within Industry	(1)	1.00				
Select Companies within Sector	(2)	0.48**	1.00			
Select Companies within Market	(3)	0.14	0.17*	1.00		
Select Industries within Sector	(4)	–0.02	0.34**	0.22**	1.00	
Select Industries within Market	(5)	–0.18*	–0.17*	0.37**	0.15	1.00
Select Sectors within Market	(6)	–0.12	–0.17*	0.28**	–0.05	0.74**

Panel C: US and Europe

			Europe Decarbonization Flows					
	Strategies		(1)	(2)	(3)	(4)	(5)	(6)
US Decarbonization Flows	Select Companies within Industry	(1)	0.05	–0.06	–0.02	–0.16*	–0.07	0.04
	Select Companies within Sector	(2)	–0.02	–0.15	–0.07	–0.10	–0.02	–0.02
	Select Companies within Market	(3)	0.09	0.02	0.00	–0.03	0.07	0.04
	Select Industries within Sector	(4)	0.05	0.00	0.06	–0.07	–0.01	–0.02
	Select Industries within Market	(5)	0.10	–0.06	–0.05	–0.08	0.12	0.14
	Select Sectors within Market	(6)	0.10	–0.02	0.03	–0.08	0.18*	0.19**

NOTES: In Exhibit 13, Panel A presents the correlation of the decarbonization flows for US strategies within the region. Panel B presents the correlation of the decarbonization flows for European strategies within the region. Panel C presents the correlation of the decarbonization flows between the two regions. ** and * indicate significance at the 5% and 10% levels, respectively.

EXHIBIT 14

Decarbonization Factor Returns and Lagged Flows

	Select Companies within Industry		Select Companies within Sector		Select Companies within Market		Select Industries within Sector		Select Industries within Market		Select Sectors within Market	
	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat	Estimates	*t*-Stat
Panel A: United States												
Controlling for All Factors												
Decarbonization Flows	0.46	2.54	0.77	3.56	0.55	1.73	0.79	1.44	0.85	1.26	0.75	1.06
Decarbonization Flows *t*–1	–0.20	–1.14	0.27	1.57	–0.21	–0.83	0.11	0.16	–1.12	–1.42	0.28	0.50
Decarbonization Flows *t*–2 to *t*–4	0.05	0.61	–0.06	–0.47	0.25	1.82	–0.08	–0.36	0.43	1.74	0.28	1.17
Controlling for Lagged Returns												
Decarbonization Flows	0.40	2.24	0.82	4.91	1.14	3.24	0.96	1.57	0.09	0.11	0.59	0.66
Decarbonization Flows *t*–1	–0.17	–1.00	0.16	0.98	–0.43	–1.16	0.44	0.55	0.36	0.42	1.07	1.56
Decarbonization Flows *t*–2 to *t*–4	0.02	0.23	–0.12	–0.97	0.19	1.22	–0.28	–0.99	0.12	0.52	–0.06	–0.21
Panel B: Europe												
Controlling for All Factors												
Decarbonization Flows	0.59	3.26	0.40	2.52	0.68	3.04	2.05	5.24	2.25	4.01	3.09	2.52
Decarbonization Flows *t*–1	–0.07	–0.39	–0.40	–2.12	–0.32	–1.29	–0.36	–0.88	–0.77	–1.20	–0.67	–0.75
Decarbonization Flows *t*–2 to *t*–4	0.01	0.16	–0.03	–0.27	–0.02	–0.21	–0.09	–0.46	–0.01	–0.05	–0.01	0.03
Controlling for Lagged Returns												
Decarbonization Flows	0.50	3.09	0.48	3.10	1.10	3.46	1.85	4.42	3.37	3.90	4.56	2.63
Decarbonization Flows *t*–1	–0.03	–0.17	–0.48	–2.23	–0.26	–0.69	–0.19	–0.39	–1.13	–1.18	–0.83	–0.54
Decarbonization Flows *t*–2 to *t*–4	0.01	0.17	0.04	0.48	–0.19	–1.16	0.07	0.27	–0.55	–1.44	–0.72	–1.37

NOTES: Exhibit 14 presents estimated coefficients on decarbonization flows from calendar time regressions of a decarbonization factor. *Controlling for all factors* is the model from Exhibit 4 while adding one-month lagged decarbonization flows and cumulative lagged decarbonization flows from months $t-2$ to $t-4$. *Controlling for lagged returns* is a model as in Exhibit 4 but instead of controlling for the factors tabulated it includes a one-month lagged of the decarbonization factor returns as a control.

associated with returns while contemporaneous flows are positive, this would suggest the presence of price pressure effects.

Results are presented in Exhibit 14. To explore the price pressure hypothesis, we include lagged flows and contemporaneous flows in the same model. We include one-month lag flows in the model but also cumulative lagged flows over the past 2 to 4 months to detect any longer reversals. Across the specifications, the coefficients on lagged flows are insignificant. We estimate several variations of this model by including or excluding other factors, and across all specifications, we fail to find a negative and statistically significant association between lagged flows and returns. Finally, we estimate a model that controls for one-month lag decarbonization factor returns to control for trend-chasing patterns and the relationship between lagged returns and flows (Froot, O'Connell, and Seasholes 2001). Again, the estimated coefficients on lagged decarbonization flows are insignificant. Here, we focus specifically on flow–return relationships rather than on residual flow–return relationships after controlling for a full set of factors, as our aim is to gauge trend-following and price reversal effects, regardless of how these may coincide with any other factors.

Combining Factors

Our results suggest that there are multiple ways to decarbonize a portfolio—a decarbonization factor performs better when its contemporaneous flows are positive and the cross-correlation of flows and returns across factors is low enough to provide opportunities to combine factors. Given these inferences, in this section, we combine factors to create new decarbonization factors. In contrast to the analysis in the Decarbonization Factor Flows in Decarbonization Strategies section and Exhibit 12, which does not provide a way for an investor to satisfy a need for decarbonization, because it forces negative exposure to decarbonization factors for some months, our analysis seeks to provide a factor that always has exposure to a decarbonized portfolio.

In Panel A of Exhibit 15, we first show the *t*-statistics of the alphas for the 12 decarbonization factors and use them as benchmarks for the composite portfolios. Then, we implement rule-based factor combinations that consider contemporaneous flows. We combine factors across geographies but not across strategies. For each of the six strategies, we either choose the US or European decarbonization factor in each month, depending on which region has higher decarbonization flows for that month. The *t*-statistics for alphas improve in 10 of 12 cases. For example, the *t*-statistic for the rule-based combined factor is 3.17 for the select sectors within market strategy. This is higher than the *t*-statistics for the United States and Europe, which are 1.82 and 2.63, respectively. Panel A of Exhibit 16 shows the performance of this rule-based combined factor across all six different strategies, which is not explained by other factors.

In Panel B of Exhibit 15, we start by creating a baseline composite decarbonization factor that does not account for flows. We create the combined decarbonization factors by taking the average across all 6 decarbonization factors within each region or 12 across both regions. Combining all 6 factors within each region or all 12 across both regions creates factors with Sharpe ratios of 0.41, 0.12, and 0.31 for the United States, Europe, and the United States plus Europe, respectively. The alphas for the three regions are 0.91%, 3.07%, and 2.22%, respectively. Only the last two estimates are statistically significant.

Next, we implement rule-based factor combinations that consider contemporaneous flows. For each region, we combine the strategies that have positive flows and take an average across factors to construct the new portfolios for the United States and Europe. We also create a combined US and European portfolio by selecting decarbonization factors with positive flows in the two regions. The Sharpe ratios increase to 0.98, 0.81, and 0.95 for the United States, Europe, and the United States plus Europe, respectively. The alphas for the three regions are 3.3%, 5.9%, and 5.3%, respectively. All three estimates are statistically significant. Panel B of Exhibit 16 shows the performance of this factor that is not explained by other factors.

We also construct portfolios by selecting factors each month with the most positive contemporaneous flows. For each region, we select the one decarbonization factor with the highest flows in the region. The combined US and European portfolio selects one decarbonization factor out of the six US and six European factors with the highest flows. The Sharpe ratios increase to 0.67, 0.82, and 1.07 for the United States, Europe, and the United States plus Europe, respectively. The alphas for the three regions are 3.2%, 6.5%, and 6.5%, respectively. All three estimates are statistically significant. Panel C of Exhibit 16 shows the performance of this factor that is not explained by other factors.

We further tested the difference in average abnormal returns between the rule-based composite portfolios and the regional or combined regional (United States plus Europe) average, as shown in Panel C of Exhibit 15. Our flow-based composite

EXHIBIT 15

Decarbonization Factor Combinations

Panel A: *t*-Statistics of Alphas for US and European Decarbonization Factors and a Strategy that Invest in Region with More Positive Contemporaneous Flows

	All Decarbonization Factors					
Strategies	**Select Companies within Industry**	**Select Companies within Sector**	**Select Companies within Market**	**Select Industries within Sector**	**Select Industries within Market**	**Select Sectors within Market**
US Decarbonization Factors	0.01	–0.84	1.31	–0.03	1.70	1.82
European Decarbonization Factors	0.72	2.40	3.60	1.84	2.02	2.63
Strategy That Chooses the Regional Factor with More Positive Contemporaneous Flows	1.25	2.34	3.58	2.43	2.44	3.17

Panel B: Performance for Composite Portfolios

Combination Rules	**All Decarbonization Factors**			**All Decarbonization Factors with Positive Flows**			**Decarbonization Factors with the Most Positive Flows**		
Region	**US**	**Europe**	**US & Europe**	**US**	**Europe**	**US & Europe**	**US**	**Europe**	**US & Europe**
Returns	1.42%	0.44%	0.94%	3.93%	3.61%	3.65%	3.52%	4.31%	5.34%
Risk	3.46%	3.56%	3.01%	4.03%	4.47%	3.85%	5.25%	5.27%	4.98%
Sharpe Ratio	0.41	0.12	0.31	0.98	0.81	0.95	0.67	0.82	1.07
Alpha	0.91%	3.07%	2.22%	3.25%	5.94%	5.29%	3.19%	6.46%	6.53%
Alpha (*t*-Stat)	1.00	2.70	3.58	2.77	5.78	5.52	2.05	4.63	3.68

Panel C: *t*-Tests in Difference in Abnormal Returns for Composite Portfolios

		Combine Decarbonization Factors with Positive Flows Relative to Regional Factor Average	**Combine Decarbonization Factors with Most Positive Flows Relative to Regional Factor Average**
United States	Estimate	2.33%	2.27%
	P-Value	0.010	0.056
Europe	Estimate	2.87%	3.38%
	P-Value	0.000	0.007
United States + Europe	Estimate	3.07%	4.30%
	P-Value	0.000	0.002

NOTES: Panel A of Exhibit 15 shows the *t*-statistics for alphas for US and European decarbonization factors and a composite strategy that chooses the regional factor with more positive contemporaneous flows. These *t*-statistics are estimated from regressions based on nonoverlapping monthly data, controlling for market, size, value, profitability, investment, and momentum factors and returns of the NYMEX oil spot.

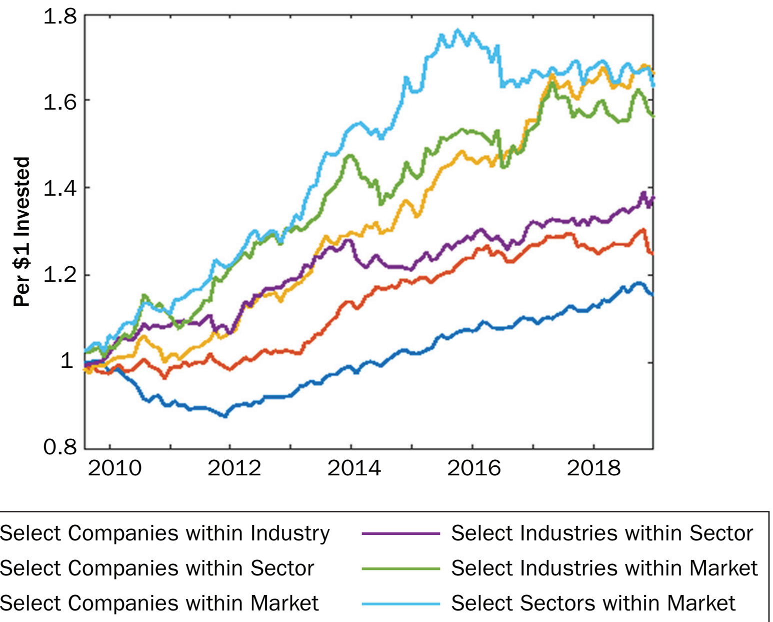
Panel B of Exhibit 15 presents the average annual returns, risk (standard deviation of returns), Sharpe ratio (return over risk), and estimated alpha and *t*-statistic from calendar time (monthly) regressions of a decarbonization factor, as in Exhibit 4. *All decarbonization factors* constructs a factor by taking the average across all 6 decarbonization factors within each region or 12 across both regions. *All decarbonization factors with positive flows* constructs a factor by taking the average across all decarbonization factors that have positive contemporaneous flows in a given month. If no decarbonization factor has positive flows, we assume the portfolio is invested in cash with zero returns. Out of a total of 114 sample months, 19 months of the combined US portfolio, 3 months of the combined European portfolio, and 1 month of the combined US and European portfolio are in cash. *All decarbonization factors with most positive flows* constructs a factor selecting each month the decarbonization factor that has the most positive flows.

Panel C of Exhibit 15 presents the estimates and p-values from *t*-test in difference in abnormal returns between the composite portfolios based on flows and the regional or combined regional (United States + Europe) average. Abnormal returns are estimated from nonoverlapping monthly calendar regressions of decarbonization factor returns on the Fama–French five factors (market, size, value, profitability, and investments) and momentum. The combined decarbonization factors within the United States, Europe, and United States + Europe are constructed by taking the average across all decarbonization factors within each region or across both regions. Composite US, European, and US + European decarbonization factors with positive flows construct a factor by taking the equally weighted average across all decarbonization factors with positive contemporaneous flows in a given month. Composite US, European, and US + European decarbonization factors with the most positive flows construct a factor by taking the average across all decarbonization factors that have the highest positive contemporaneous flows in a given month. If no decarbonization factor has positive flows, we assume the portfolio is invested in cash with zero returns.

EXHIBIT 16

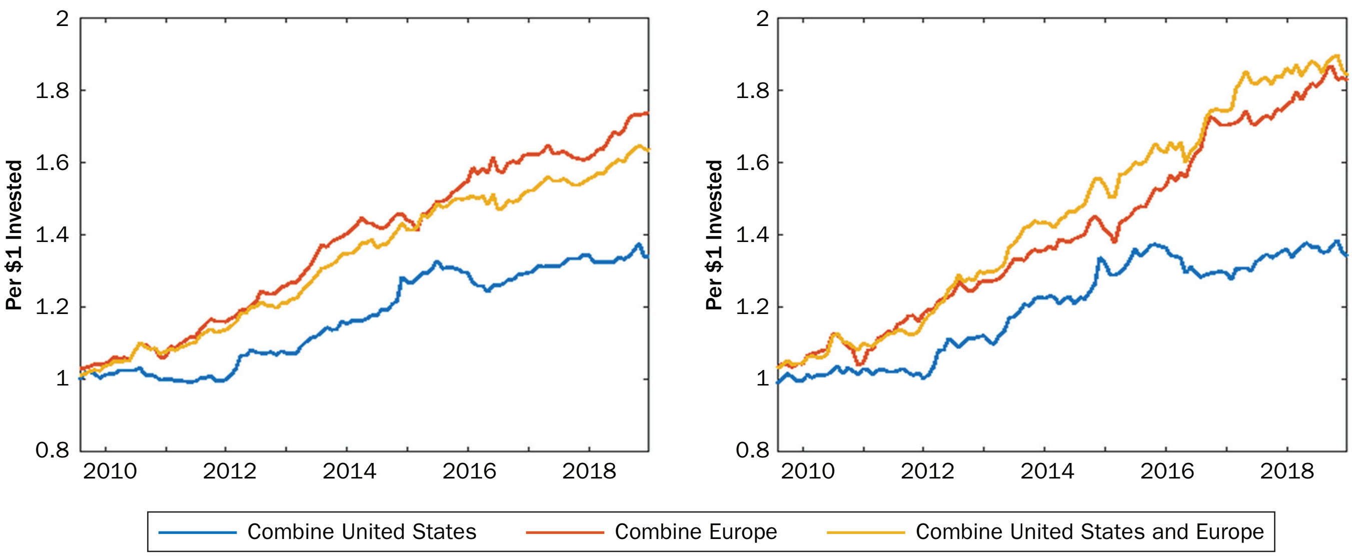
Cumulative Performance of Abnormal Returns for Combined Decarbonization Factors

Panel A: Select Decarbonization Factor across Regions Based on Contemporaneous Flows



Panel B: Combine Decarbonization Factor within and across Regions Based on Contemporaneous Flows

Panel C: Combine Decarbonization Factor within and across Regions Based on Highest Contemporaneous Flows



NOTES: Exhibit 16 represents the cumulative performance for abnormal returns for a $1 investment in the combined decarbonization factors. In Panel A, we combine factors across regions but not across strategies. For each of the six strategies, we choose either the US or European factor, depending on which region has higher decarbonization flows. In Panel B, for each region, we combine the strategies that have positive decarbonization flows and take an average across factors to construct the combined portfolios for the United States and Europe. A combined US and European factor is also created by selecting decarbonization factors with positive flows in the two regions. In Panel C, for each region, we select only one decarbonization factor that has the highest flows in the region. The combined US and European portfolio selects the one decarbonization factor out of the six US and six European factors with the highest flows.

portfolios perform economically and statistically better than the simple regional average portfolios. Overall, the results suggest that rotating across factors based on flows has the potential to improve the performance of decarbonization factors significantly.

CONCLUSION

In this article, we examine the construction of decarbonization factors. These factors have much lower carbon emissions but differ significantly in how much they reduce their exposure to carbon emissions. Moreover, they generate different risk-adjusted returns. We observe stronger positive alphas in Europe compared with the United States in our sample. This finding is consistent with the more positive economics for decarbonization strategies in European economies over the time period of our article. We find a strong positive contemporaneous relationship between decarbonization factor flows and factor returns across most decarbonization strategies. The decarbonization factors perform consistently well, delivering positive and significant alpha, when contemporaneous flows are positive. Our results suggest that institutional investor flows contain information about the returns of decarbonization strategies.

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