HARVARD | BUSINESS | SCHOOL

Decarbonization Factors

Alex Cheema-Fox
Bridget R. LaPerla
George Serafeim
David Turkington
Hui Wang

Working Paper 20-037

Decarbonization Factors

Alex Cheema-Fox
State Street Associates

David Turkington
State Street Associates

Bridget R. LaPerla
State Street Associates

Hui Wang
State Street Associates

George Serafeim
Harvard Business School,
State Street Associates

Working Paper 20-037

Funding for this research was provided in part by Harvard Business School.

Decarbonization Factors

Alex Cheema-Fox, Bridget R. LaPerla, George Serafeim, David Turkington and Hui Wang*

August 20th, 2019

Abstract

In the face of accelerating climate change, investors are making capital allocations seeking to decarbonize portfolios by reducing the carbon emissions of their holdings. To understand the performance of portfolio decarbonization strategies and investor behavior towards decarbonization we construct decarbonization factors that go long low carbon intensity sectors, industries, or firms and short high carbon intensity. We consider several portfolio formation strategies and find 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 US. Our results suggest that institutional investor flows contain information about anticipated fundamentals related to climate change developments.

Keywords: climate change, ESG, investment management, factor investing, investor behavior

* Alex Cheema-Fox, Bridget Realmuto LaPerla, David Turkington and Hui Wang are with State Street Associates®. George Serafeim is the Charles M. Williams Professor of Business Administration at Harvard Business School and a partner at State Street Associates. We are grateful for input from State Street Associates' researchers Edward Cuipa, and Michael Guidi and assistance from Megan Czasonis, Baykan Pamir, Eric Rahn, Matthew J. Van Vlack and Travis Whitmore.
SSA JD 2019-08

1. Introduction

While 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. Today, the concentration of carbon emissions is at its highest level in over 800,000 years, at 413 parts per million, which substantially exceeds all natural fluctuations and the prior high of 300 parts per million, reached over 300,000 years ago.[1] A preponderance of evidence suggests that this rise is a direct result of human economic activities since the Industrial Revolution.

The increase in carbon emissions concentration gives rise to several physical effects, such as sea level rise and droughts, but also to regulatory and technological responses in search for a solution. Assuming warming gets to 2-degrees Celsius, climate change could inflict $69 trillion in damage on the global economy by 2100.[2] More recent estimates from the Intergovernmental Panel on Climate Change (IPCC) forecasts between 2- and 4-degrees Celsius rise by 2100, thereby raising the level of likely economic effects.

Against this backdrop, many investors seek to limit the carbon emissions of the firms 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 firms with the lowest carbon intensity within an industry or sector. While 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

---

[1] Daily CO2. *CO2.Earth*. Available at: https://www.co2.earth/daily-co2 [Accessed June 25, 2019]; Lüthi, D. et al., 2008. High-Resolution Carbon Dioxide Concentration Record 650,000–800,000 Years before Present. *Nature Publishing Group*, 453(7193), pp.379–82. https://doi.org/10.1038/nature06949

[2] Muffson, S. (2019). *Moody's Analytics says climate change could cost $69 trillion by 2100*. The Washington Post. Available at: https://www.washingtonpost.com/climate-environment/moodys-analytics-says-climate-change-could-cost-69-trillion-by-2100/2019/07/02/f9fb94ac-99cb-11e9-916d-9c61607d8190_story.html?noredirect=on [Accessed June 25, 2019].

news (Engle et al. 2018), our study seeks to document how different decarbonization strategies yield varying results both in terms of risk-adjusted returns and carbon intensity. Moreover, given that many investors are now pursuing decarbonization strategies we are interested to understand if institutional flows to decarbonization strategies relate to returns, as investors incorporate information about climate change into their investment processes.

Our data span from 2009 to 2018 for the US and Europe. We analyze these two geographic segments as they have responded differently to climate change. Admittedly Europe has responded more aggressively to climate change, by instituting a pricing system for carbon emissions (EU ETS). This provides more systematic market incentives for businesses to lower their carbon emissions due to 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 firms to 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 where we classify sectors according to across-firm average carbon intensity. The second and third are industry approaches where we classify industries within sectors or within the whole market according to across-firm 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 it is less carbon intensive relative to other industries in the sector, while in the second it will be classified as carbon intensive. The last three strategies are firm-level classifications. They separate firms based on carbon intensity within an industry, sector, or the market.

We create decarbonization factors for each strategy, buying low carbon intensity sectors, industries, or firms 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) but also for oil returns and the decarbonization flows. The analyses suggests 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 with the within market strategies (i.e. not conditioning within sector or industry) 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 suggests that demand for stocks with low carbon intensity has pricing effects. This could be 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 between 1.48 and 4.43% in the US 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 US and Europe. For example, combining factors with most positive flows across both US and Europe creates a decarbonization strategy that delivers a positive and significant alpha of 6.53% annually during the period of our study.

Our paper contributes to a growing literature on how climate change impacts investor expectations, capital allocations and thereby pricing and returns (Anderson, Bolton and Samama 2016; Choi, Gao and Jiang 2019; Alok, Kumar and Wermers 2019; Engle et al. 2019). 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 are the likely performance and carbon exposure differences across strategies.

2. Background and Motivation

2.1. Background to Climate Change

The increase in carbon emissions concentration gives rise to several physical effects that impact businesses, the economy, and investors' portfolios. It has already led to an increase of 1.0 degree Celsius in average global temperature since 1880 and an average sea-level rise of over 2.6 inches, with the rate of annual increases accelerating.[3] A phenomenon particularly important given that today, approximately 3 billion people, about 40% of the world's population live within 200 kilometers of a coastline.[4] By 2025, that figure is likely to double given urbanization trends.

In the Paris agreement of 2016 countries made voluntary commitments in an attempt to limit global temperature rise to 2.5 degrees Celsius. However, the 2014 release of the Fifth Intergovernmental Panel on Climate Change (IPCC) forecasted between a 2 and 4 degrees Celsius 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 current trends in carbon emissions.[5] This 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 meter, though more recent projections are calling for as much as a 2 meters rise, displacing

[3] Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, et al. (eds.), World Meteorological Organization, Geneva, Switzerland "Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty Headline Statements from the Summary for Policymakers," Intergovernmental Panel on Climate Change (IPCC), 2018. *IPCC Expert Meeting on Assessing Climate Information for Regions* [Accessed July 9, 2019]; 2008. Is Sea Level Rising? National Oceanic and Atmospheric Administration National Ocean Service, US Department of Commerce, Available at: https://oceanservice.noaa.gov/facts/sealevel.html [Accessed July 9, 2019].

[4] Creel, L., 2003. Ripple Effects: Population and Coastal Regions. *Population Reference Bureau*. Available at: https://www.prb.org/rippleeffectspopulationandcoastalregions/ [Accessed July 9, 2019].

[5] IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Chapter 12, 1032.; Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, et al. (eds.), World Meteorological Organization, Geneva, Switzerland "Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty Headline Statements from the Summary for Policymakers," Intergovernmental Panel on Climate Change (IPCC), 2018. *IPCC Expert Meeting on Assessing Climate Information for Regions* [Accessed July 9, 2019].

hundreds of millions of people globally.[6] Further, the UN has already linked climate change to increasing land degradation and desertification to rising hunger, exemplified by severe water shortages in major metropolitan areas of Cape Town and Chennai.[7] 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 at those in the United States, it would take five planets to support it.[8]

Companies are responding to the physical, regulatory and market changes brought by climate change. Thousands of companies have now set corporate-wide 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 that all aim to move the economy towards a low carbon future.

2.2. 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 lower carbon footprint. New York State Common Retirement Fund allocated $4 billion to a low emissions index that tilts holdings towards

---

[6] IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Chapter 13, 1140.; Jonathan L. Bamber el al., 2019. Ice sheet contributions to future sea-level rise from structured expert judgment. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*. Available at: https://www.pnas.org/content/116/23/11195 [Accessed July 9, 2019].

[7] 2018. UN Warns Climate Change is Driving Global Hunger. *The United Nations Framework Convention on Climate Change (UNFCCC)*, Available at: http://unfccc.int/news/un-warns-climate-change-is-driving-global-hunger [Accessed July 9, 2019].

[8] Country Overshoot Days 2019. *Earth Overshoot Day.* Available at: https://www.overshootday.org/newsroom/infographics/ [Accessed July 9, 2019].

companies with lower carbon footprint.[9] The portfolio's footprint is 75% lower than the Russell 1000 index.[10] In 2014, the Fourth Swedish national fund AP4 announced its intention to decarbonize its equity portfolio by 2020. New Zealand Superannuation Fund shifted its global passive equity portfolio (NZ$14 billion) to be managed against a low-carbon benchmark. NZ Super approved a target to reduce the carbon-emission intensity of the fund by at least 20% and reduce the carbon reserves exposure of the Fund by at least 40% by 2020. US Public Pension Fund CalSTRS committed US$2.5 billion to low-carbon index in U.S., non-U.S. 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. French Reserve Fund (FRR) adopted new equity benchmarks to halve its carbon emissions from standard indices. 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 GHG emission by 75%-80% and cut exposure to fossil fuel reserves by 85%-90%.

2.3. Portfolio Decarbonization Strategies

Most decarbonization strategies seek to limit the carbon profile of the portfolio by underweighting high carbon emission firms and overweighting low carbon emission firms. 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 firm and the latter, Scope 2, are the carbon

---

[9] 2018. New York Pension Fund Doubles Bet on Low-Carbon Companies. *The Wall Street Journal.* Available at: https://www.wsj.com/articles/new-york-pension-fund-doubles-bet-on-low-carbon-companies-1517320801 [Accessed July 9, 2019].

[10] 2018. Low-carbon investing and low-carbon indices. *United Nations Principles for Responsible Investment (UNPRI).* Available at: https://www.unpri.org/climate-change/low-carbon-investing-and-low-carbon-indices/3283.article [Accessed July 9, 2019].

emissions generated by purchased electricity. Scope 3 emissions which include emissions outside the boundaries of operational control of a firm, either downstream, generated by product use by the customer, or upstream, generated by a firm's supply chain are not typically considered. This is because only a very small number of firms calculate them, and even within the set of firms that calculate and disclose them, the methodologies tend to vary significantly, impairing the comparability of numbers across firms. Because carbon emissions are greatly influenced by firm scale, the most frequently used measure is carbon intensity where carbon emissions are scaled by firm sales.

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

3. Data

3.1. Carbon Data

We use security level Scope 1 and Scope 2 carbon intensity data (moving on addressed 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 firms with large operations to those with smaller operations, to assess how efficiently these firms 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.[11]

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 is 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 cap 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 is within the first 100 trading days of Trucost data coverage.

3.2. Price Data

Prices and (free-float) market capitalizations are sourced from Morgan Stanley Capital International (MSCI), taken from the ACWI IMI universe of securities. Stocks are assigned to countries and regions based upon the MSCI classification and to industries and sectors using the GICS classification system. Returns are computed in USD and are derived from MSCI total return indices.

[11] 2015. World Business Council for Sustainable Development & World Resources Institute, *The Greenhouse Gas Protocol*, Revised Edition 24-33.

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 firms within industry, we first allocate firms into low carbon and high carbon groups within an industry based on whether the firm's carbon intensity is smaller or greater than the industry median. We market-cap weight the firms 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 six regional strategies, for twelve strategies total.

$$Decarbonization\ Factor\ Returns_{select\ firms\ within\ industry} =$$

$$\sum_{i}^{\substack{all \\ industries}} \left\{ \left[\sum_{s \in L(i)}^{securities} return_s \cdot \frac{marketCap_s}{\sum_{s \in L(i)} marketCap_s} - \sum_{s \in H(i)}^{securities} return_s \cdot \frac{marketCap_s}{\sum_{s \in H(i)} marketCap_s} \right] \times \frac{marketCap_i}{\sum_i^{all\ industries} marketCap_i} \right\}$$

Where "*H(i)*" denotes the set of high carbon securities in industry i and "*L(i)*" denotes low carbon securities in industry i, and s denotes securities. The market capitalization weight of the industry is computed as the industry market capitalization (US and Europe respectively) relative to the total regional market capitalization (of the US and Europe respectively).

3.3. 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.[12] 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 study, we focus on flows linked to the universe of MSCI securities described in our market data section above. This dataset has been previously investigated in the context of country equity by Froot, O'Connell, and Seasholes (2001), who found evidence of both 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:

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

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 paper. Active flows may be interpreted as capturing intra-fund 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:

[12] All analysis of flow indicators was performed within State Street's secure environment and was subject to aggregation, anonymization and smoothing through time to protect client confidentiality.

$$flow_{security} = \sum\nolimits_{funds} flow_{security,fund}.$$

Holdings are aggregated across funds analogously; below 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 aggregating these spreads across industries (or sectors) to generate a single market level series.

$$Decarbonization\ Flows_{select\ firms\ within\ industry} =$$

$$\sum_{i}^{\substack{all\\industries}} \left[\left\{ \left(\sum_{s \in L(i)}^{securities} \frac{flow_s}{holdings_s} \cdot \frac{marketCap_s}{\sum_{s \in L(i)} marketCap_s} - \sum_{s \in H(i)}^{securities} \frac{flow_s}{holdings_s} \cdot \frac{marketCap_s}{\sum_{s \in H(i)} marketCap_s} \right) \right\} \times \frac{marketCap_i}{\sum_i^{all\ industries} marketCap_i} \right]$$

In the above, "*H(i)*" denotes the set of high carbon securities in industry *i* and "*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 capitalization weight of the industry is computed as the industry market cap (US and Europe respectively) relative to the total regional market cap (of the US 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.

3.4. Data Mapping

We mapped the Trucost security level carbon intensity data to MSCI market data using ISINs. For each company, we used MSCI time-series code as the main identifier which allows us to keep track of companies historically, even companies that go through name and ISIN changes. We then mapped this dataset to State Street's proprietary custodial flows and holdings data. We included companies with a market cap of $2 billion, adding and removing those companies when we form 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 remove observations for a company if there is 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 through December 31, 2018. As of the end of the 2018, a total of 2,149 companies and over 34 trillion US dollars mid- and large-cap (over USD$2 billion) listed equities mapped to our active institutional flows data. Among these companies, 1,403 are US listed companies and 746 are Europe listed companies, according to MSCI classifications. Summary statistics of our samples are provided in Table 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 and 3.5 billion for the US and Europe respectively.[13]

3.5. Multi-factor Model Estimation

[13] 2018. GlobalCarbonAtlas.org. *CO2 Emissions | Global Carbon Atlas.* Available at: http://www.globalcarbonatlas.org/en/CO2-emissions. [Accessed 19 Aug. 2019].

We form long-short portfolios on the last trading day of June from 2009 to 2018 and hold the portfolios for one year. In each region, we have three select firms decarbonization portfolios, two select industries portfolios and one select-sector portfolio. For the select firms within industry portfolio, firms within each industry are allocated into two groups – the low carbon risk (the long side) and the high carbon risk (the short side) – depending on whether the firm'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 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 firms within sector portfolio is sector-neutral and constructed in similar fashion, while select firms within market portfolio has no constraint and the sorting is across all sectors and industries. The two select-industries portfolios and one select-sectors portfolio are built in the same way, except that the underlying data are at industry or sector level instead of the firm level.

Once a portfolio is formed, there is no rebalance between portfolio formation dates. On rare occasions where a firm's stock is delisted, or an industry is discontinued, or a firm'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 US and 6 for Europe, we setup a time-series multi-factor framework where we regress the decarbonization factor returns on the Fama-French 5 factors — including market, size, value, profitability and investment factors — and the momentum factor, NYMEX oil spot returns as well as the corresponding portfolio's decarbonization flows, shown in the equation below.[14]

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

As described in Section 3.3, we engineered the decarbonization flows to reflect the real- money buying and selling across high carbon and low carbon groups at firm, industry or sector level, based on State Street's institutional investor flows and holdings 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 firm, industry, or sector levels for a given portfolio specification. 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 are able to investigate the relationship between the flows and decarbonization factors, or how the decarbonization factors' performances align with investors' decarbonization behavior for the first time in literature. The model also controls for oil returns, since 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

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

overlapping period from July 2009 to December 2018. Heteroskedasticity and autocorrelation consistent standard errors are used to compute the t-statistics and level of significance.

4. Results

4.1. Performance of Decarbonization Factor

Figure 1 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 firms within market decarbonization factors in the US is remarkably strong. In Europe, select firms within industry or within sector factors are also strong.

Figure 2 demonstrates the daily active investor flows for each decarbonization factor and illuminates a striking difference for flows in Europe and in the US. 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 decline in the US after the 2016 change in presidential administration.

In Table 2 we observe economically and statistically significant positive alpha for select firms within sector and within market factors in Europe. The decarbonization factors exhibit strong negative relation to the profitability factor and in three cases to the oil factor. Both relations are stronger for decarbonization factors that select firms within market suggesting that imposing sector or industry constraints produces portfolios that are less correlated to other factors.

The alphas for the US select industries and select sectors within market factors are marginally significant at the 10% level. The decarbonization factors exhibit strong negative correlation to the investment factor and to 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. Figure 3 plots the cumulative abnormal returns for all different strategies.

All decarbonization factors both in Europe and US exhibit a positive relation with the flow factor. In nine of the twelve factors this relationship is statistically significant. Flows seem to be associated with more positive returns on the decarbonization factor.

4.1.1. Correlation of Decarbonization Factor Returns across Strategies

Table 3 shows univariate correlations between 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 firms within industry or sector exhibit stronger correlation with select industries or sectors in the US compared to Europe. The lower cross-correlations in Europe suggest that investors have both more opportunities for diversification in Europe but also that the choice of the decarbonization strategy produces a wider spectrum of results. Between US and Europe, only the select firms within market, select industries within market, and select sectors within market are highly correlated. This also suggests opportunities for diversification across strategies.

4.2. Portfolio Decarbonization

We calculate for each strategy its portfolio decarbonization (PD), measured as the market capitalization weighted carbon intensity of the short portfolio, minus the market capitalization weighted carbon intensity of the long portfolio, over the market capitalization 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.

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

The strategies exhibit very different PDs. The more we constrain our portfolio construction, the less we decarbonize the portfolio. For example, select securities within market has a higher PD, compared to select securities within sector, which has higher PD compared to select securities within industry. The results can be seen in Table 4. In the US, for the select firms portfolios within market, sector and industry the PD are 2.07, 1.41 and 1.15 respectively. The PDs for the select industries within sector, select industries within market and select sectors within market are 1.36, 2.84, and 3.35 respectively. In Europe the PDs for the portfolios that select firms within market, sector and industry are 2.00, 1.25 and 1.07 respectively. The PDs for the select industries within sector, select industries within market and select sectors within market are 0.97, 2.08 and 2.07 respectively.

A few more observations are worth noting. Moving from select firms within market to select firms within sector decreases significantly 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%). 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. Thereby, an investor that wants to hold all industries in the long portfolio will bear a significant carbon penalty.

4.3. 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 Figure 4. 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 US 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 name it carbon footprint reduction.[15] Figure 5 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 US and Europe.

4.4. 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. Figure 6 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 US. For example, in the US for the select firms within market portfolio, the decarbonization factor with positive flows grows to \$1.30 by 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.

[15] 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) then divided by the carbon emissions of the market to capture the amount of carbon reduction.

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

Table 5 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 US select sectors and industries strategies. In contrast, the negative flow decarbonization factor delivers negative alphas in most of the strategies; however, the alphas are only significant in the cases of US select firms within sector. This suggests that the alphas in Table 5 are mostly driven by longing the decarbonization factors when flows are positive rather than shorting the factor when flows are negative.

4.4.1. Correlation of Decarbonization Factor Flows across Strategies

Table 7 shows univariate correlations between decarbonization factor flows across all strategies. Panel A shows results for US, Panel B for Europe and Panel C between US and Europe. For most strategy pairs we find significantly stronger positive correlation in the US rather than in Europe. In fact, flows for the best-in-class approaches, select firms 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 firm selection within industry or sector. Flows across the two geographic regions exhibit very low correlation when using the same strategy.

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

Results are presented in Table 6. To explore the price pressure hypothesis, we include lagged flows and contemporaneous flows in the same model. We include both 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 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.

4.6. 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 section 4.4. and Table 5, which does not provide a way for an investor to satisfy a need for decarbonization as 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 Table 8 we start by creating a baseline composite decarbonization factor that does not account for flows. We created the combined decarbonization factors by taking the average across all six decarbonization factors within each region or 12 across both regions. Combining all six factors within each region or all 12 across both regions creates factors with Sharpe Ratios of 0.41, 0.12 and 0.31 for US, Europe and US plus Europe respectively. The alphas for the three regions are 1.3, 2.8 and 2.3% respectively. Only the last two estimates are statistically significant.

Next, we implement rules-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 US and Europe. We also create a combined US and European portfolio selecting decarbonization factors with positive flows in the two regions. The Sharpe Ratios increase to 0.98, 0.81 and 0.95 for US, Europe and US plus Europe respectively. The alphas for the three regions are 3.8, 5.9 and 5.2% respectively. All three estimates are statistically significant.

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-European portfolio selects one decarbonization factor out of the 6 US and 6 European factors with the highest flows. The Sharpe Ratios increase to 0.67, 0.82 and 1.07 for US, Europe and US plus Europe respectively. The alphas for the three regions are 3.2, 6.5 and 6.5% respectively. All three estimates are statistically significant. Overall, the results suggest that rotating across factors based on flows has the potential to improve the performance of decarbonization factors significantly.

We also present the change in abnormal returns relative to each factor in each region. The results can be seen in Table 9 and show the performance of decarbonization factors that combine all six factors within each region or all 12 factors across both regions relative to the performance of the strategy within the geographic region. In Panel A, we do not find a consistent and meaningful improvement in performance after combining the factors. In six cases, the estimates of the mean of abnormal returns improve significantly, in four cases it declines significantly, and in 14 cases, there is no statistical difference in the estimate.

Next, we implement rules-based factor combinations that consider contemporaneous flows. First, in Panel B 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. In eleven out of twelve cases the abnormal returns increase significantly. Figure 7A shows the performance of this factor across all six different strategies, which is not explained by other factors.

Second, in Panel C, for each region, we combine the strategies that have positive contemporaneous flows, and take an average across factors to construct the new portfolios for US and Europe. We also create a combined US and European portfolio selecting decarbonization factors with positive flows in the two regions. In 23 out of 24 cases the abnormal returns increase significantly. Figure 7B shows the performance of this factor that is not explained by other factors.

Third, in Panel D, for each region we select only one decarbonization factor that has the highest contemporaneous flows in the region. The combined US-European portfolio selects one decarbonization factor that has the highest flows, out of the 6 US and 6 European factors. In 23 out of 24 cases the abnormal returns increase significantly. Figure 7C shows the performance of this factor that is not explained by other factors.

5. Conclusion

In this paper we examined 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 to the US in our sample. This is consistent with more positive economics for decarbonization strategies in European economies over the time period of our study. 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.

References

Andersson M., Bolton P. and Samama F. 2016. Hedging climate risk. *Financial Analysts Journal* 72(3), 13-32

Alok S., Kumar N. and Wermers R. 2019. Do Fund Managers Misestimate Climatic Disaster Risk?, Working Paper.

Amel-Zadeh A. and Serafeim G. 2018. Why and How Investors Use ESG Information: Evidence from a Global Survey. *Financial Analysts Journal* 74(3), 87-103

Baker M., Bergstresser D., Serafeim G. and Wurgler J. 2018. Financing the Response to Climate Change: The Pricing and Ownership of U.S. Green Bonds. *National Bureau of Economic Research,* Working Paper 25194

Bansal R., Ochoa M. and Kiku D. 2017. Climate Change and Growth Risks. *National Bureau of Economic Research.* Working Paper 23009

Choi D., Gao Z., Jiang W. 2019. Attention to Global Warming. *Review of Financial Studies*, Forthcoming

Engle R. F., Giglio S., Lee H., Kelly B. and Stroebel J. 2019. Hedging Climate Change News, *National Bureau of Economic Research.* Working Paper 25734

Fama E. F. and French K. R. 2017. International tests of a five-factor asset pricing model. *Journal of Financial Economics* 123(3), 441-463

Froot K. A., O'Connell P. G. J. and Seasholes M. S. 2001. The portfolio flows of international investors. *Journal of Financial Economics* 59, 151-193

Froot K. and Teo M. 2008. Style Investing and Institutional Investors. *Journal of Financial and Quantitative Analysis* 43(4), 883-906

Ioannou I., Li X. and Serafeim G. 2017. The Effect of Target Difficulty on Target Completion: The Case of Reducing Carbon Emissions. *The Accounting Review* 91(5), 1467-1492

Kotsantonis S. and Serafeim G. 2019. Four Things No One Will Tell You About ESG Data. *Journal of Applied Corporate Finance* 31(2), 50-58

Figure 1: Cumulative Performance for Decarbonization Factors

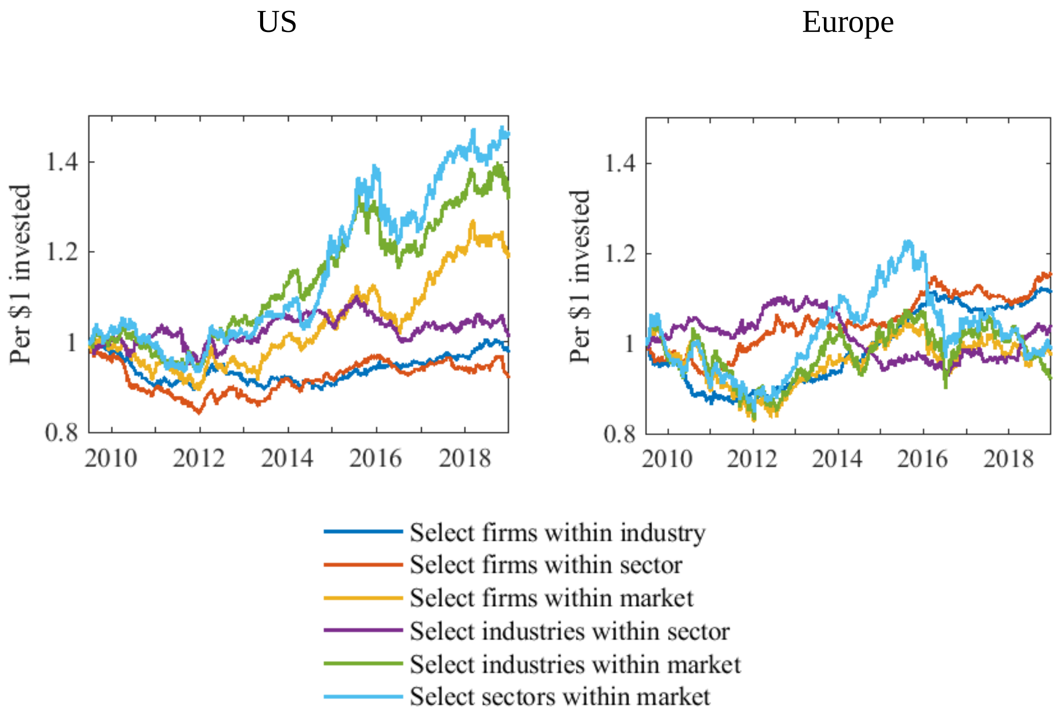


Figure 1 presents cumulative performance for $1 investment in the decarbonization factors from July 1, 2009 to December 31, 2018. All decarbonization factors are constructed from long-short portfolios that are formed on the last trading day of June each year, with a holding period of one year. For the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

Figure 2: Cumulative Decarbonization Factor Flows

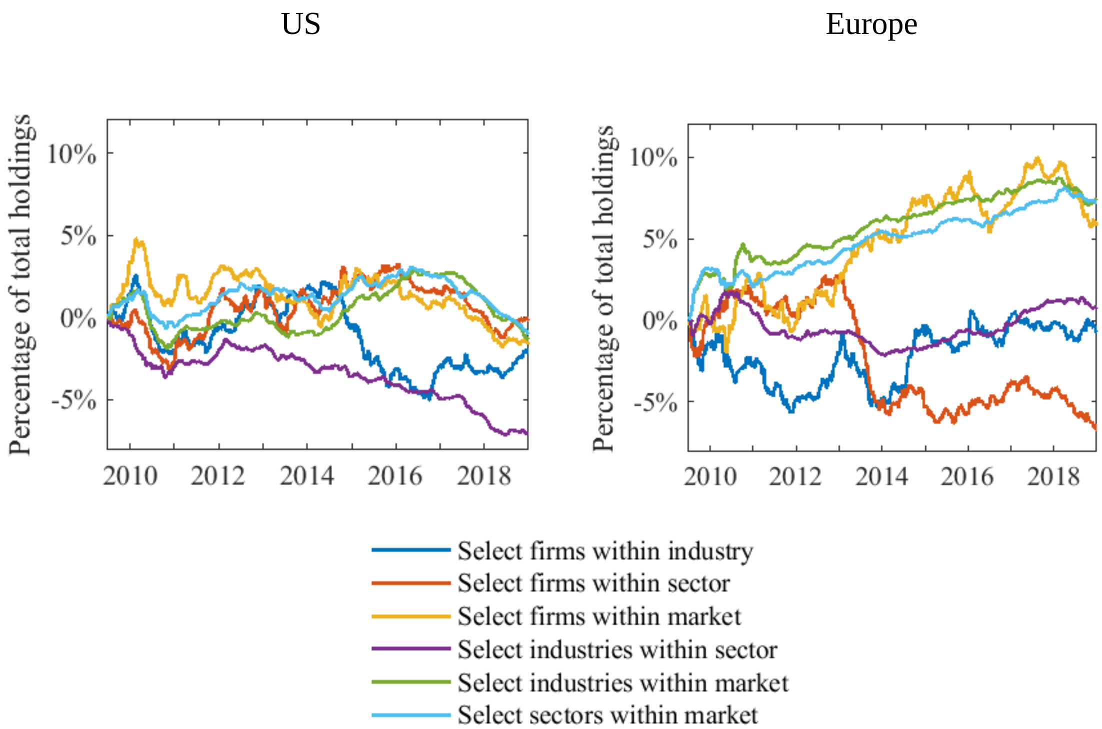


Figure 2 presents cumulative decarbonization flows that correspond to the decarbonization factors from July 1, 2009 to December 31, 2018. The vertical axis is in percentage of total holdings. The different portfolio formation strategies for the decarbonization factor are described in the text.

Figure 3: Cumulative Abnormal Returns for Decarbonization Factors

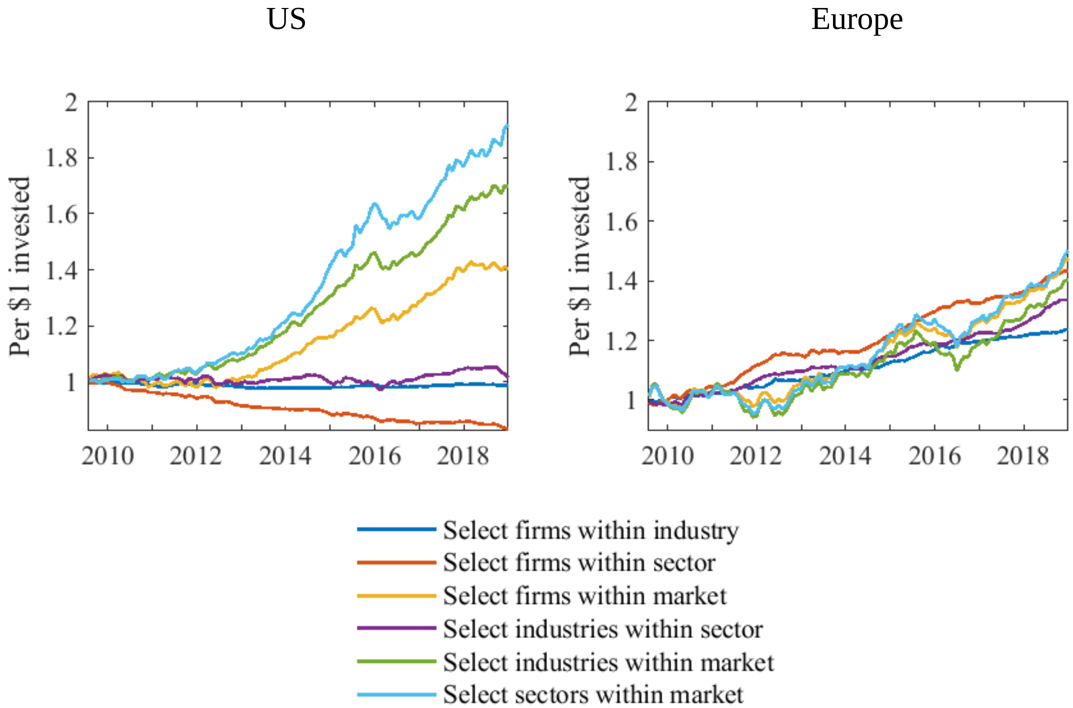
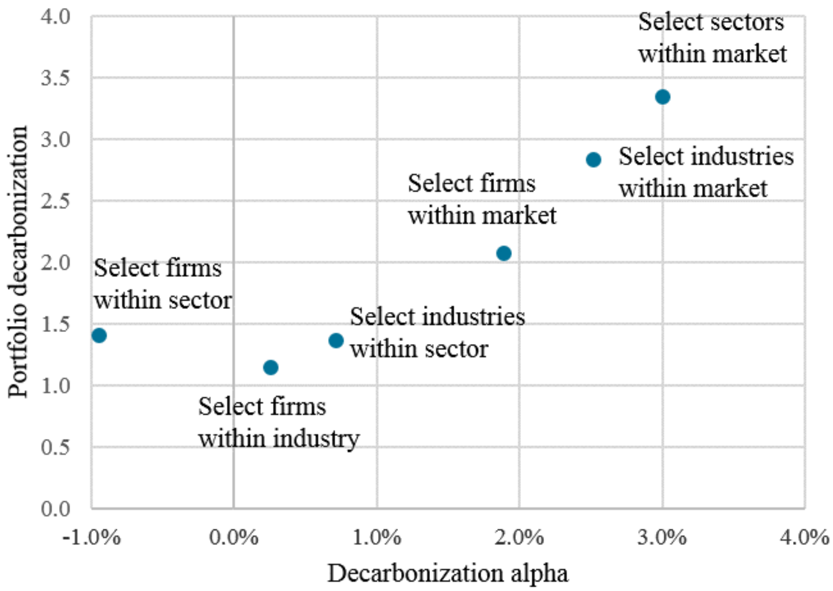


Figure 3 presents cumulative abnormal returns for $1 investment in the decarbonization factors from July 1, 2009 to December 31, 2018. The abnormal returns are estimated from regressions based on non-overlapping monthly data, controlling for market, size, value, profitability, investment, momentum factors and returns of NYMEX oil spot.

Figure 4: Portfolio Decarbonization and Decarbonization Alpha

US



Europe

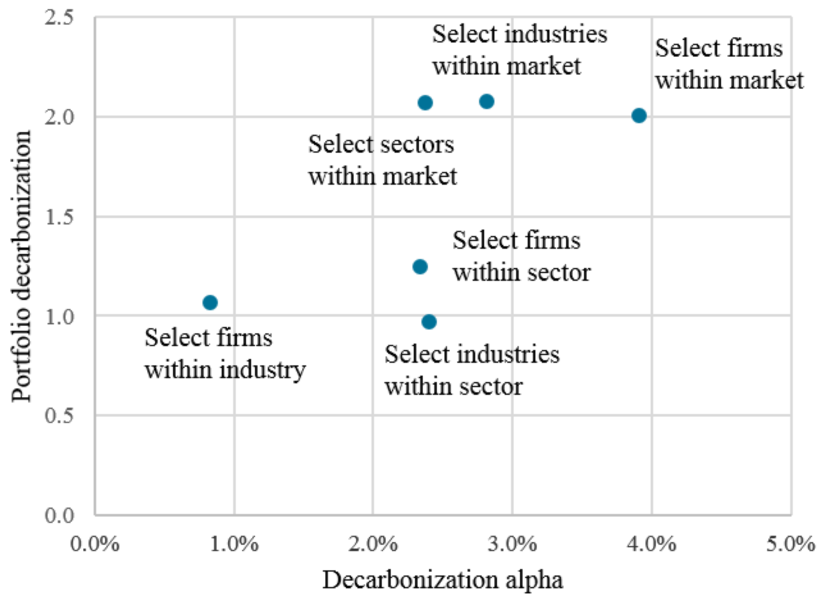
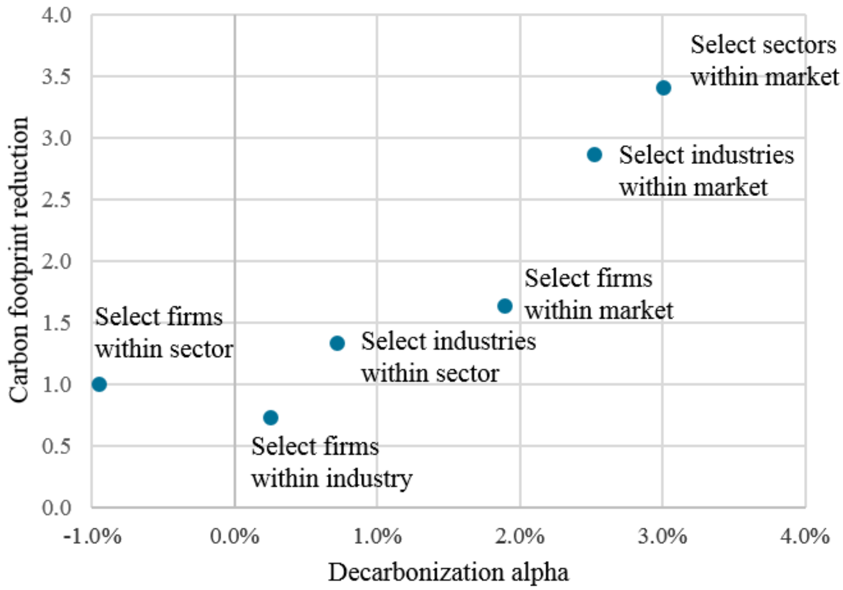


Figure 4 presents portfolio decarbonization versus decarbonization alpha for the six portfolios in each region. For each strategy, we calculate the portfolio decarbonization (PD) measured as the market capitalization weighted carbon intensity of the short portfolio (higher carbon intensity group) minus the market capitalization weighted carbon intensity of the long portfolio (lower carbon intensity group) over the market capitalization 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. $PD = \frac{carbon\ intensity_{portfolio,\ Short} - carbon\ intensity_{portfolio,\ Long}}{carbon\ intensity_{market}}$

Figure 5: Portfolio Carbon Footprint Reduction and Decarbonization Alpha

US



Europe

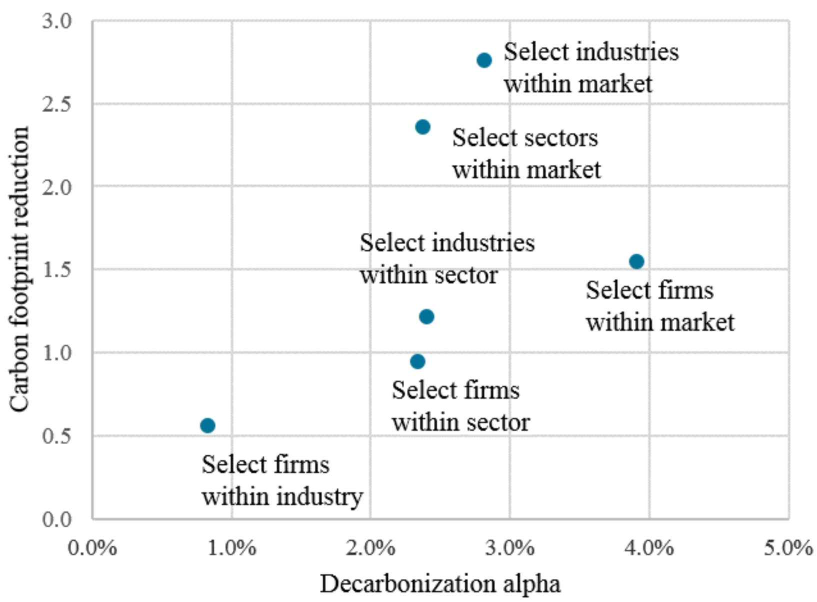


Figure 5 presents portfolio carbon footprint reduction versus decarbonization alpha for the six portfolios in each region. The carbon footprint reduction is calculated per strategy as the low carbon emission securities (or industries or sectors) from the high carbon emission securities (or industries or sectors) then divided by the carbon emissions of the market to capture the amount of carbon reduction. $carbon\ footprint\ reduction = \frac{carbon\ emission_{portfolio,\ Short} - carbon\ emission_{portfolio,\ Long}}{carbon\ emission_{market}}$

Figure 6: Cumulative Performance for Decarbonization Factors

Conditional on the Sign of Decarbonization Flows

US

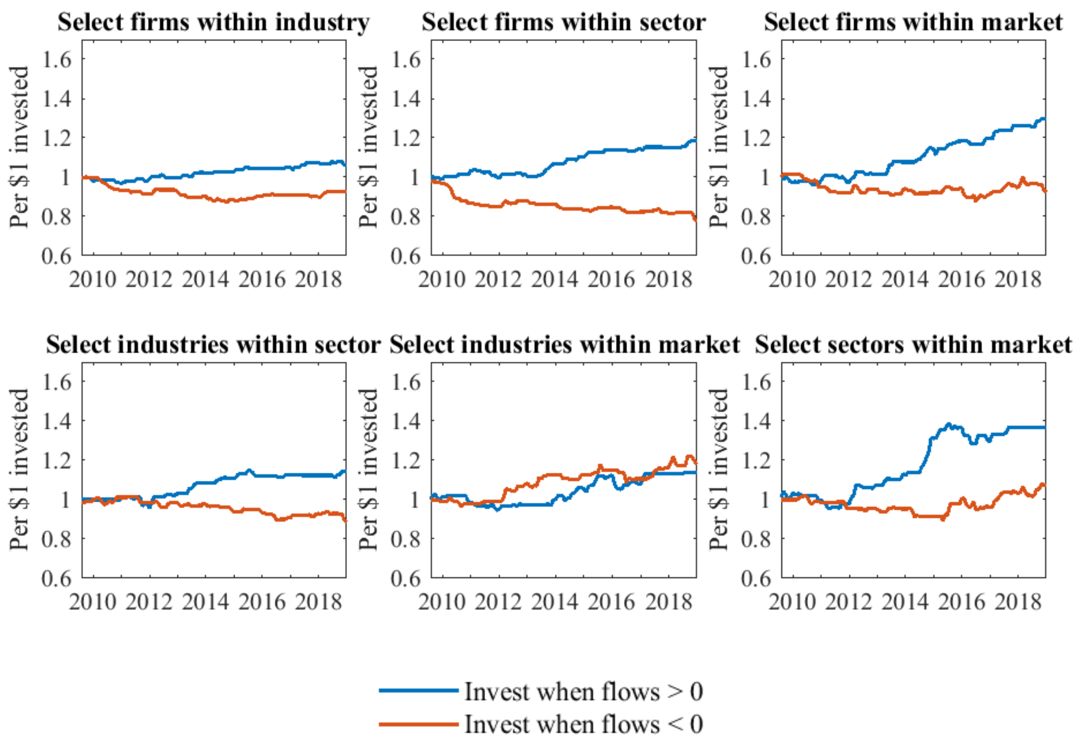


Figure 6: (Continued)

Europe

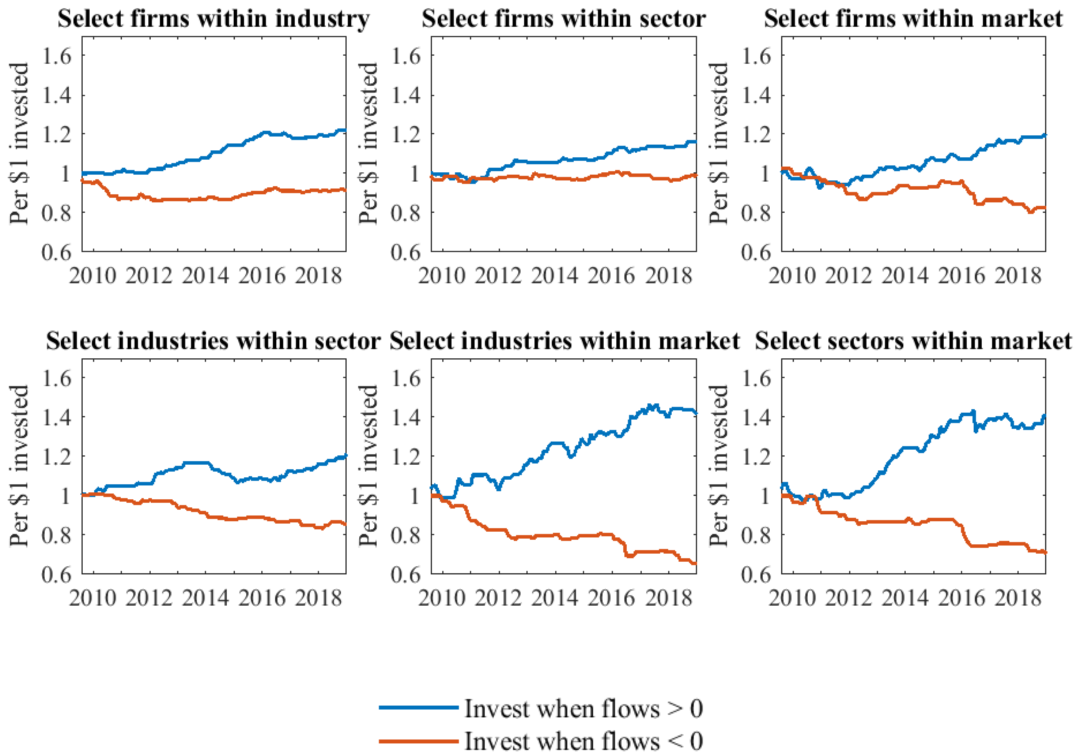
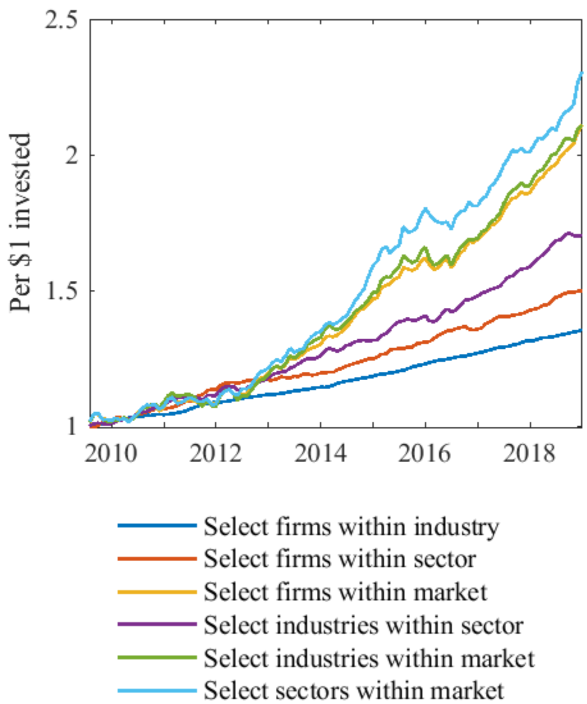


Figure 6 represents the cumulative performance for $1 investment in the decarbonization factors conditional on the sign of the flows in US and Europe. For each decarbonization factor, we created two portfolios (blue and red in the graphs). One portfolio (blue) invests in the factor when flows are positive, and invests in cash with zero returns when flows are negative. The other portfolio (red) invests in the factor when flows are negative, and invests in cash with zero returns when flows are positive.

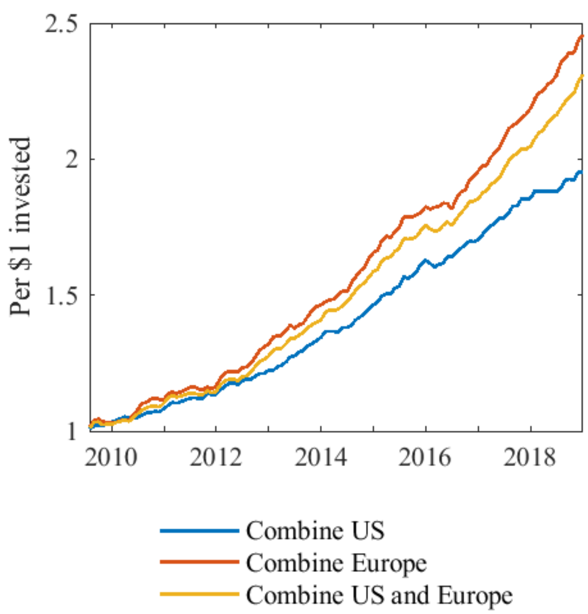
Figure 7: Cumulative Performance of Abnormal Returns

for Combined Decarbonization Factors

A: Select decarbonization factor across regions based on contemporaneous flows



B: Combine decarbonization factor within and across regions based on contemporaneous flows



C: Combine decarbonization factor within and across regions based on the highest contemporaneous flows

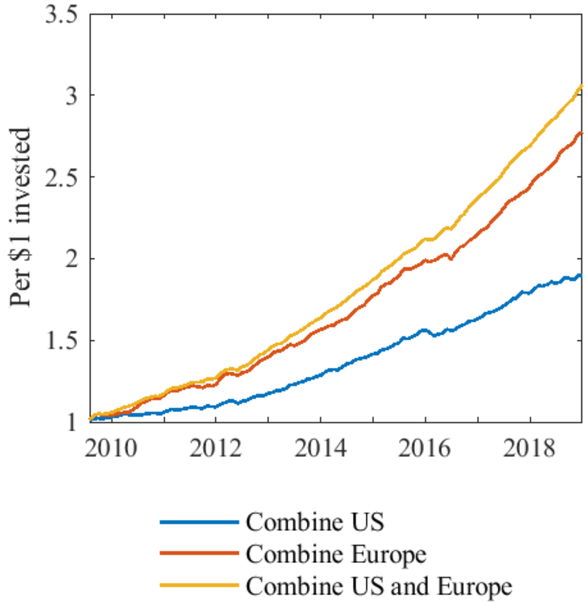


Figure 7 represents the cumulative performance for abnormal returns for $1 investment in the combined decarbonization factors. In Figure 7A, we combine factors across regions but not across strategies. For each of the six strategies, we either choose the US or European factor depending on which region has higher decarbonization flows. In Figure 7B, for each region, we combine the strategies that have positive decarbonization flows, and take an average across factors to construct the combined portfolios for US and Europe. A Combine US and European factor is also created selecting decarbonization factors with positive flows in the two regions. In Figure 7C, 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 6 US and 6 European factors, with the highest flows.

Table 1: Investable Universe Summary Statistics

Panel A: US

Year	Number of Unique Firms	Total Market Cap (in billion $)	Mcap-Weighted Carbon Intensity (in tonnes carbon emissions/mil$)	Total Carbon Emissions (in tonnes carbon emissions)
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

Year	Number of Unique Firms	Total Market Cap (in billion $)	Mcap-Weighted Carbon Intensity (in tonnes carbon emissions/mil$)	Total Carbon Emissions (in tonnes carbon emissions)
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

The tables present summary statistics of our samples for the US and European market from July 2009 to December 2018. This reflects a universe of securities with daily timestamped carbon, fundamental, flows and holding data with a market cap at or over $2 billion. Details on the sample selection process are described in Section 3 of the paper.

Table 2: Regression on Decarbonization Factor Returns

Panel A: US

	Select firms within industry		Select firms within sector		Select firms 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
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

	Select firms within industry		Select firms within sector		Select firms 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
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

Table 2 presents estimates and t-statistics from non-overlapping 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.

Table 3: Correlation of Decarbonization Factor Returns across Strategies

Panel A: US

Strategies		(1)	(2)	(3)	(4)	(5)
Select firms within industry	(1)	1.00				
Select firms within sector	(2)	0.51**	1.00			
Select firms 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 firms within industry	(1)	1.00				
Select firms within sector	(2)	0.57**	1.00			
Select firms 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: US and Europe

			Europe Decarbonization Factors					
	Strategies		(1)	(2)	(3)	(4)	(5)	(6)
US Decarbonization Factors	Select firms within industry	(1)	0.15*	0.16**	0.07	-0.14**	0.08	0.06
	Select firms within sector	(2)	0.22*	0.21**	-0.04	-0.03	-0.03**	-0.01
	Select firms 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**

Table 3 Panel A (B) presents univariate correlations between returns to the US (Europe) decarbonization factor constructed using different strategies. Panel C presents univariate correlations between decarbonization factor returns in the US and in Europe. The decarbonization factor goes long on low carbon intensity sectors, industries or firms and short on high carbon intensity sectors, industries or firms. Noting that **indicates the value is significant at 5% level, and * at 10% level.

Table 4: Portfolio Decarbonization Statistics

Region	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
US	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

In Table 4, we calculate the portfolio decarbonization (PD) for each strategy. PD is measured as the market capitalization weighted carbon intensity of the short portfolio minus the market capitalization weighted carbon intensity of the long portfolio over the market capitalization 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. $PD = \frac{carbon\ intensity_{portfolio,\ Short} - carbon\ intensity_{portfolio,\ Long}}{carbon\ intensity_{market}}$

Table 5: Decarbonization Factor Performance Conditional on Flows

Region	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
US						
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

Table 5 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 non-overlapping monthly data from July 2009 through December 2018. The models control for all other factors (as in Table 2) except for decarbonization flows.

Table 6: Decarbonization Factor Returns and Lagged Flows

Panel A: US

	Select firms within industry		Select firms within sector		Select firms 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
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

	Select firms within industry		Select firms within sector		Select firms 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
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

Table 6 presents estimated coefficients on decarbonization flows from calendar time regressions of a decarbonization factor. *Controlling for all factors* is the model from Table 2 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 Table 2 but instead of controlling for the factors tabulated it includes a one-month lagged of the decarbonization factor returns as a control.

Table 7: Correlation of Decarbonization Factor Flows across Strategies

Panel A: US

Strategies		(1)	(2)	(3)	(4)	(5)
Select firms within industry	(1)	1.00				
Select firms within sector	(2)	0.54**	1.00			
Select firms 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 firms within industry	(1)	1.00				
Select firms within sector	(2)	0.48**	1.00			
Select firms 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

	Strategies		Europe Decarbonization Flows (1)	(2)	(3)	(4)	(5)	(6)
US Decarbonization Flows	Select firms within industry	(1)	0.05	-0.06	-0.02	-0.16*	-0.07	0.04
	Select firms within sector	(2)	-0.02	-0.15	-0.07	-0.10	-0.02	-0.02
	Select firms 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**

In Table 7, 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. Noting that **indicates the value is significant at 5% level and * at 10% level.

Table 8: Decarbonization Factor Combinations

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	1.25%	2.82%	2.31%	3.78%	5.94%	5.24%	3.19%	6.46%	6.53%
Alpha (t-stat)	1.43	3.38	3.08	2.48	5.87	5.56	2.05	4.63	3.68

Table 8 presents the average annual returns, risk (standard deviation of returns), Sharpe Ratio (return over risk), and the estimated alpha and t-statistic from calendar time (monthly) regressions of a decarbonization factor as in Table 2. *All decarbonization factors* constructs a factor by taking the average across all six 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 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. Flows in this analysis are contemporaneous.

Table 9: Decarbonization Factor Combinations by Strategy

Panel A: Difference in Abnormal Returns after combining all Decarbonization Factors

		All Decarbonization Factors					
Combination - Relative to Factor	*Strategies*	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
Combine US factor - US Factor	Estimate	2.87%	4.70%	-0.90%	2.55%	-2.93%	-4.26%
	p-value	0.000	0.000	0.103	0.001	0.000	0.000
Combine European factor - European Factor	Estimate	1.07%	-0.47%	-0.87%	0.26%	-0.39%	-1.08%
	p-value	0.238	0.663	0.209	0.745	0.730	0.257
Combine US+ European factor - US Factor	Estimate	3.44%	5.27%	-0.33%	3.12%	-2.37%	-3.69%
	p-value	0.000	0.000	0.678	0.000	0.002	0.001
Combine US+ European factor - European Factor	Estimate	1.04%	-0.51%	-0.90%	0.23%	-0.43%	-1.11%
	p-value	0.213	0.605	0.364	0.773	0.758	0.370

Panel B: Difference in Abnormal Returns Choosing Region with More Positive Contemporaneous Flows into Decarbonization Factor

		US or Europe More Positive Flows into Decarbonization Factor					
Combination - Relative to Factor	*Strategies*	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
Combine US+ European factor - US Factor	Estimate	3.36%	6.25%	4.33%	5.47%	2.31%	1.95%
	p-value	0.000	0.000	0.000	0.000	0.014	0.039
Combine US+ European factor - European Factor	Estimate	0.96%	0.47%	3.76%	2.58%	4.25%	4.52%
	p-value	0.016	0.331	0.000	0.000	0.000	0.000

Panel C: Difference in Abnormal Returns after combining all Decarbonization Factors with Positive Contemporaneous Flows

		All Decarbonization Factors with Positive Flows					
Combination - Relative to Factor	*Strategies*	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
Combine US factor - US Factor	Estimate	7.24%	9.07%	3.46%	6.92%	1.43%	0.10%
	p-value	0.000	0.000	0.000	0.000	0.020	0.912
Combine European factor - European Factor	Estimate	7.29%	5.74%	5.35%	6.48%	5.82%	5.13%
	p-value	0.000	0.000	0.000	0.000	0.000	0.000
Combine US+ European factor - US Factor	Estimate	9.04%	10.86%	5.26%	8.71%	3.23%	1.90%
	p-value	0.000	0.000	0.000	0.000	0.000	0.084
Combine US+ European factor - European Factor	Estimate	6.63%	5.08%	4.69%	5.82%	5.16%	4.48%
	p-value	0.000	0.000	0.000	0.000	0.000	0.000

Panel D: Difference in Abnormal Returns after Choosing Decarbonization Factor with Most Positive Contemporaneous Flows

		Decarbonization Factor with Most Positive Flows					
Combination - Relative to Factor	*Strategies*	Select firms within industry	Select firms within sector	Select firms within market	Select industries within sector	Select industries within market	Select sectors within market
Combine US factor - US Factor	Estimate	6.94%	8.77%	3.16%	6.62%	1.13%	-0.20%
	p-value	0.000	0.000	0.000	0.000	0.010	0.840
Combine European factor - European Factor	Estimate	8.57%	7.02%	6.63%	7.76%	7.10%	6.42%
	p-value	0.000	0.000	0.000	0.000	0.000	0.000
Combine US+ European factor - US Factor	Estimate	12.01%	13.84%	8.24%	11.69%	6.20%	4.88%
	p-value	0.000	0.000	0.000	0.000	0.000	0.000
Combine US+ European factor - European Factor	Estimate	9.61%	8.06%	7.67%	8.80%	8.14%	7.46%
	p-value	0.000	0.000	0.000	0.000	0.000	0.000

The Panels within Table 9 present means and p-values for differences in abnormal returns after and before we combine decarbonization factors. In Panel A, we created the combined decarbonization factors by taking the average across all six decarbonization factors within each region or 12 across both regions. We then calculate the difference in abnormal returns between the combinations and the relative factors. The means of the difference and the p-values from t-tests are provided in the table. In Panel B, we combine factors across regions but not across strategies. For each of the six strategies, we either choose the US or European factor depending on which region has higher decarbonization flows. In Panel C, for each region, we combine the strategies that have positive decarbonization flows, and take an average across factors to construct the combined portfolios for US and Europe. A Combine US and European factor is also created selecting decarbonization factors with positive flows in the two regions. In Panel D, 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 6 US and 6 European factors, with the highest flows.