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Low Carbon Mutual Funds*

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Abstract

Climate change poses new challenges for portfolio management. In our not-yet-low carbon world, investors face a trade-off between minimizing their exposure to climate risks and maximizing the benefits of portfolio diversification. This article investigates how investors and financial intermediaries navigate this trade-off. After the release of Morningstar's novel carbon risk metrics in April 2018, mutual funds labeled as "low carbon" experienced a significant increase in investor demand, es-pecially those with high risk-adjusted returns. Fund managers actively reduced their exposure to firms with high carbon risk scores, especially stocks with returns that correlated more with the funds' portfolios and were thus less useful for diversifica-tion. These findings shed light on whether and how climate-related information can re-orient capital flows in a low carbon direction.

Keywords: Behavioral finance, Portfolio management, Climate change, Investor preferences, Mutual funds, Sustainable finance

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1. Introduction

How should investors behave in the face of climate-related risks and the energy transition to a low carbon world? To answer this question, it is important to recognize that account-ing for climate risks in investment decisions brings investors both benefits and costs.

On the one hand, shunning carbon-intensive, "brown" assets can reduce an investor's exposure to climate risks. These risks have yet to fully materialize, both in terms of physical consequences and societal reactions, and many observers believe that they are currently underestimated in asset prices (Stroebel and Wurgler, 2021). On the other hand, in our not-yet-low carbon economy, excluding "brown" assets and investing only in those considered "green" require investors to forego opportunities to diversify. This trade-off is particularly salient in asset management, where portfolio diversification, not only the features of indi-vidual securities, plays a crucial role in reducing overall investment risk (Markowitz, 1952).

In this article, we study how investors and asset managers navigate this trade-off. We focus on the mutual fund industry, which represents an important share of global financial markets,[1] and exploit a quasi-natural experiment involving a sudden increase in both the availability and salience of information on carbon risk (climate transition risk), that is, the class of risk deriving from the transition to a lower carbon economy. As we describe in more detail in Section 2, on April 30, 2018, Morningstar, the most important data provider in the mutual fund industry, released a new Portfolio Carbon Risk Score derived from firm-level data provided by Sustainalytics, which Morningstar has controlled since 2017. The novelty of Morningstar's Portfolio Carbon Risk Score is highlighted by the fact that it cor-relates only mildly with other portfolio metrics, based on previously available environmen-tal scores from Sustainalytics, Refinitiv, and MSCI KLD. Based on its new carbon risk score, combined with relatively standard information on firms' fossil fuel involvement (FFI), Morningstar also issued an eco-label for mutual funds—the low carbon designation (LCD). We use a large sample of active European and US mutual funds to study investors' and fund managers' reactions to these information shocks produced by the publication of Morningstar's Portfolio Carbon Risk Score and its associated LCD eco-label.

We develop the conceptual framework guiding our empirical analyses in Section 3. We first confirm that, in line with extant literature (e.g., Engle et al., 2020; Bolton and Kacperczyk, 2021a), individual low carbon securities are less risky than other firms, both in terms of exposure to negative climate change news and realized return volatility. We then shift our focus to the portfolio level. One may naively think that the risk properties of low carbon funds should mirror those of their low carbon holdings. Such, we find, is not the case. The investment risk of a portfolio depends not only on the variance of its individ-ual holdings' returns, but also on the covariance of these returns (Markowitz, 1952). Empirically, while low carbon funds have lower exposure to climate risks, their volatility is not lower than that of more conventional funds. In fact, we find that the mutual funds with the lowest carbon risk scores have higher volatility than those with median scores. The source of this result is the high degree of industry concentration (Kacperczyk, Sialm, and Zheng, 2005) of low carbon funds. These funds overweight IT, retail, and healthcare firms,

1 In 2020, open-end mutual funds had some USD 63 trillion in assets under management worldwide, representing around 26% of equity and debt securities outstanding (Investment Company Institute, 2021).

while they underweight energy, materials, and utility firms. Beyond the industry concentra-tion, the fact that low carbon funds hold fewer stocks does not significantly further explain their surprisingly high volatility. Overall, low carbon funds hold assets that, although indi-vidually less risky, have a high degree of covariance, limiting risk-sharing.

In Section 4, we study the reactions of mutual fund investors to the April 2018 informa-tion shock. Funds receiving the "Low Carbon Designation" enjoyed a substantial increase in their monthly flows relative to other funds. The economic impact of the LCD label corre-sponds to an average increase in flows of approximately 36 basis points each month through the end of 2018; this increase is equal to about two-thirds of the effect on flows caused by a one-standard-deviation stronger monthly financial performance.

Before the new data became available, investors likely used Morningstar's sustainability Globes as an imperfect proxy for exposure to carbon risk. Intuitively, if a fund with few Globes received the LCD, it would come as a larger surprise to investors. Consistent with this logic, we find larger effects on flows in such situations. In addition, LCD-labeled funds with strong risk-adjusted performance experienced a more pronounced flow premium. Moreover, after the publication of the LCD list—but not before—qualifying for the low carbon eco-label resulted in particularly large extra flows in months of greater attention to climate change, as measured by Google search intensity. All these results are consistent with investors taking both the benefits and the costs into account when investing in low car-bon funds.

In Section 5, we employ a dataset of monthly portfolio holdings to study the reactions of fund managers to the release of Morningstar's portfolio and firm-level carbon risk infor-mation. We show that, after April 2018, fund managers actively rebalanced their portfolios to reduce their carbon risk. On average, relative to the period before the publication of Morningstar's carbon risk metrics, mutual funds reduced their position in the average high carbon risk firm by about 0.17 basis points of their assets under management (AUM) per month. This effect is economically meaningful, considering that the median monthly pos-ition change is zero for the whole sample and 2.8 basis points for non-zero position changes.

Managers reacted to carbon risk not only with a one-shot rebalancing of their port-folios, but also by integrating the new information into their flow-driven investment deci-sions after the initial shock. In particular, we observe that funds experiencing large negative net flows sold high carbon risk assets more aggressively than did other funds, while funds experiencing high inflows increased their stakes in low carbon risk assets.

Further cross-sectional evidence indicates that, as we expected, funds with higher ex ante industry concentration reacted more strongly to the release of the new carbon risk in-formation. For these funds, shifting to lower carbon risk assets is less likely to decrease (and may even increase) their diversification. They are also likely to serve clients who are less interested in broad diversification in the first place. Importantly, we find that when managers reduced their positions in stocks with a score of medium or high carbon risk, they did so more aggressively for those with a higher return covariance with the remainder of the portfolio, consistent with an attempt to preserve diversification.

This article contributes, first, by providing insights into the benefits and costs of green investment products. Existing research suggests that firms with better environ-mental performance have lower exposure to climate-related risks, and are priced ac-cordingly (e.g., Engle et al., 2020; Bolton and Kacperczyk, 2021a, 2021b; Huynh and Xia, 2021; Ilhan, Sautner, and Vilkov, 2021; Ramelli et al., 2021b; Hsu, Li, and Tsou,

2022). However, how the risk properties of individual green securities translate to the portfolio level is still largely unexplored and, as we show, not obvious. The trade-off at the portfolio level that we highlight in this context is consistent with the theoretical lit-erature on green investing.[2]

Second, we complement the literature on whether and why investors prefer socially responsible investment products (e.g., Bollen, 2007; Renneboog, ter Horst, and Zhang, 2011; Riedl and Smeets, 2017; Bassen et al., 2019; Hartzmark and Sussman, 2019; Barber, Morse, and Yasuda, 2021; Bauer, Ruof, and Smeets, 2021; Geczy, Stambaugh, and Levin, 2021; Anderson and Robinson, 2022). The responses to the quasi-natural experiment that we analyze highlight both the costs and benefits of socially responsible investment products, crucial for understanding the complexity of investor behavior on sustainability issues. In terms of costs, low carbon investing asks investors to pay a price in terms of lower sectoral diversification, at least in the short term. Generic sustainable ratings/products, in contrast, are usually based on "best in class" approaches precisely to allow investors to not give up any sectoral diversification. In terms of benefits, the event we analyze allows a focus on investors' specific climate-related preferences. As documented by Hartzmark and Sussman (2019), the investors we study had already self-selected into funds based on their generic sustainability preferences. Our results indicate that both the cost and benefit sides of low carbon investing shape investor responses.

Third, we complement the literature on professional money manager behavior. Several studies consider fund manager behavior as a function of traditional financial performance metrics, but in recent years, ESG factors, and climate-related considerations in particular, have gained importance in the industry. For instance, Krueger, Sautner, and Starks (2020) and Ilhan et al. (2023) provide survey evidence on the importance of climate risks for insti-tutional investors. Bolton and Kacperczyk (2021a) show that institutional investors apply carbon-related screens and Choi, Gao, and Jiang (2023) document a decrease in institution-al investors' exposure to carbon-intensive domestic firms after 2015. Fund managers change their holdings after shifts in climate risk perception due to natural disasters (Alok, Kumar, and Wermers, 2020) or extreme heat events (Alekseev et al., 2021). Gantchev, Giannetti, and Li (2022) study fund managers' trading behavior with respect to firms' sus-tainability, focusing on the price pressure implications on individual stocks. Our article contributes to this literature by studying how fund managers actively changed their port-folio holdings following increased transparency on climate risks in the mutual fund industry.

2 In Heinkel, Kraus, and Zechner (2001) and Pa´ stor, Stambaugh, and Taylor (2020b), for instance, divestment from "brown" assets is negatively related to investor risk aversion, because deviating from the market portfolio implies incurring diversification risks. Similarly, Boyle et al. (2012) explore the effects on optimal portfolios of the need to balance asset diversification ("Markowitz's view") and asset familiarity ("Keynes' view"). Wagner (2011) develops a model in which investors forgo di-versification benefits to hedge liquidation risks. Pedersen, Fitzgibbons, and Pomorski (2021) analyze optimal portfolios when considering environmental, social, and governance (ESG) risks and prefer-ences. In contemporaneous work, Hambel, Kraft, and van der Ploeg (2022) theoretically explore the interplay between governmental climate actions and portfolio diversification from a macro-finance perspective. Of course, low carbon investing can come in different shapes. For instance, Andersson, Bolton, and Samama (2016) and Bolton, Kacperczyk, and Samama (2022) outline approaches to reducing CR with small tracking errors and sector-weighted deviations.

2 Empirical Setting and Data

2.1 Empirical Setting

On April 30, 2018, Morningstar launched on its platform the Portfolio Carbon Risk Score, a measure designed to help its clients better assess a portfolio's exposure to carbon risk (also known as climate transition risk), that is, the risk due to the transition from a fossil fuel reliant economy to a lower carbon economy.[3] On the same day, Morningstar assigned its LCD label to funds with low carbon risk scores and low levels of fossil fuel exposure; this heuristic is aimed at helping clients easily identify mutual funds whose portfolios align with the transition to a low carbon economy.[4] Figure 1 shows the portfolio carbon risk score and the LCD label, as seen on Morningstar's fund report. Details on the methodology underlying these metrics are in Morningstar (2018a, 2018b).

The portfolio carbon metrics are based on firm-level carbon risk scores from the ESG data provider Sustainalytics; these scores were also disclosed for the first time at the end of April 2018.[5] The simultaneous release of firm-level and fund-level carbon risk scores was possible because Morningstar has controlled Sustainalytics since 2017 (initially with a 40% stake, which increased to 100% in 2020). According to the two data providers, the firm-level carbon risk score quantifies a company's exposure to, and management of, material climate transition risk. It attempts to capture the degree to which a firm's economic value is at risk in the transition to a low carbon economy (Morningstar, 2018b). Table A1 in the Supplementary Appendix provides the summary statistics of firm-level carbon risk scores in each Global Industry Classification Standard (GICS) sector. Firms in high-emitting sectors (e.g., energy, materials, and utilities) have the highest mean carbon risk scores, but there is substantial variability in this measure within all sectors.

To receive the LCD label, a fund has to comply with two criteria: (i) a 12-month average Portfolio Carbon Risk Score below 10 (out of 100) and (ii) a 12-month average FFI rating below 7%. As of April 2018, having a Portfolio Carbon Risk Score below 10 implies being among the 29% best-performing funds on this dimension. A 12-month portfolio FFI rating below 7% represents a 33% under-weighting of fossil fuel-related companies, relative to the global equity universe.[6]

The release of Morningstar's carbon metrics thus represented a double shock to invest-ors: a shock to the availability of carbon-related information through the firm-level and fund-level carbon risk scores and a shock to its salience through the LCD label. The arrival

3 Morningstar's carbon risk metrics do not reflect a portfolio's exposure to extreme weather events caused by climate change, although these are likely to impact firms' assets and operations and hence cause investors significant losses. For an overview of the differences between carbon risk and physical risk, see, for instance, Task Force on Climate-Related Financial Disclosures (2017).

4 See Morningstar, "Morningstar launches portfolio carbon risk score to help investors evaluate funds' carbon-risk exposure," May 1, 2018.

5 To compute its Portfolio Carbon Risk Scores, Morningstar weights the firm-level carbon risk scores by the total investment (debt and equity) that a fund holds in a given company at the end of the quarter. A Portfolio Carbon Risk Score is calculated if more than 67% of the fund's portfolio assets have a firm-level carbon risk score.

6 Sustainalytics/Morningstar classify a firm as fossil fuel involved if it derives at least 5% of its rev-enue from thermal coal extraction, thermal coal power generation, or oil and gas production or power generation, or at least 50% of its revenues from oil and gas products and services (Morningstar, 2018b).

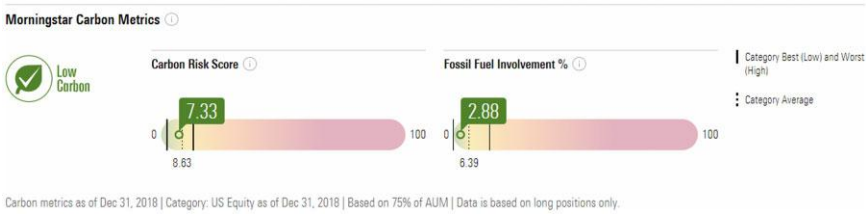

Figure 1. Morningstar direct snapshot.

of these new data is potentially relevant both to fund managers and to their clients.[7] Morningstar representatives have confirmed to us that they did not communicate the re-lease of these metrics to either fund managers or clients in advance of their publication on April 30, 2018. As seen further below, our analyses of pre-publication trends of investor and fund manager behavior are indeed consistent with the release of the new data not being anticipated.

2.2 Data

We base our analyses on two main datasets, covering the period from April 2017 (1 year before our main event of interest) to September 2019: Fund-level month-end information (from Morningstar Direct) and individual historical portfolio holdings (from Morningstar On Demand). We complement these two datasets with firm-level characteristics from Compustat Capital IQ and Sustainalytics. In what follows, we briefly describe our data.

2.2.a. Fund-level characteristics

From Morningstar Direct, we obtain survivorship-bias-free data (all in USD) for all active open-end mutual funds domiciled in Europe and the USA. To work with a relatively homo-geneous sample, we drop funds classified by Morningstar as pure fixed income, sector-specific, or investing exclusively outside the USA and Europe. We are left with twenty categories of equity and balanced funds.[8]

7 Morningstar (2018a) suggests that "Understanding portfolio carbon risk gives investors the ability to make strategic decisions to mitigate carbon risk and a basis for measuring carbon risk reduc-tion. This applies to asset managers as well as asset owners and fund investors. An asset manager can use carbon risk information to inform buy–sell and portfolio construction decisions, to make decisions on which companies to engage with to better understand their climate risk mitigation strategies and to communicate with clients and other stakeholders about their activities. An asset owner or fund investor can use carbon risk information to better understand how climate risks af-fect their investments overall and as a basis for action to reduce their exposure to climate risks. This information allows fund investors to take climate risks into consideration as they monitor, com-pare, and select funds and asset managers."

8 The twenty categories in our sample are: aggressive allocation, allocation miscellaneous, cautious allocation, equity miscellaneous, Europe emerging markets equity, Europe equity large cap, flexible allocation, global equity large cap, global equity mid/small cap, long/short equity, moderate alloca-tion, target date, UK equity large cap, UK equity mid/small cap, US equity large cap blend, US equity large cap growth, US equity large cap value, US equity mid cap, US equity small cap, and Europe equity mid/small cap. Our results also hold when using the full sample of funds domiciled in Europe and the USA, or when just focusing on pure equity funds.

While mutual funds issue several share classes to target-specific investor groups or geographies, the underlying portfolio is the same regardless of class. Consequently, we conduct our main analyses at the fund level. In aggregating data from the share class to the fund level, we compute funds' returns and volatility as value-weighted average values across dif-ferent share classes. Fund assets (in USD) are the sum of a fund's AUM in all its share classes. We require funds to have at least 1 million USD in AUM and to be at least 1 year old. We retrieve other fund-level information from each fund's largest share class.

Following Sirri and Tufano (1998), we compute flows as the monthly growth of AUM, net of reinvested returns. We winsorize flows at the 1st and 99th percentiles. Following Hartzmark and Sussman (2019), we also compute a measure of normalized flows: First, we split the sample into deciles of fund size; second, we rank funds according to net flows with-in each size decile and compute percentiles of the net flow rankings. These percentiles cor-respond to the normalized flow variable.

Return is the total monthly return (in percentage points), as reported by Morningstar. We estimate the return volatility as the standard deviation of returns over the past 12 months. We also collect other information about each fund, including its age, its Morningstar category, its financial performance rating (the Morningstar Stars, on a 1–5 scale, with 5 indicating a top financial performer), and its generic sustainability rating (the Morningstar Globes, on a 1–5 scale, with 5 indicating a top sustainability performer).

To account for the impact on flows of changes in a fund's financial performance rating (Del Guercio and Tkac, 2008), we define the variable DStars to indicate an upgrade (1) or a downgrade (–1) in the fund's Stars rating from the previous month. Similarly, to account for the impact on flows of changes in a fund's generic sustainability rating (Ammann et al., 2018; Hartzmark and Sussman, 2019), we define the variable DGlobes to indicate an up-grade (1) or a downgrade (–1) in the fund's Globes rating from the previous month. We classify observations with missing Stars or Globes as no change.

Panel A of Table I shows summary statistics for fund-month observations, from April 2017 to September 2019, for which information on flows is available. Panel B provides a snapshot of the statistics as of the end of April 2018. The sample covers some 13,600 funds, of which 17–18% obtained Morningstar's LCD eco-label.

Panel A in Table A2 in the Supplementary Appendix shows the geographical distribu-tion of our sample as of April 2018. Around 9,000 funds are domiciled in Europe and 4,000 in the USA, of which 18% received the initial LCD. Panels B and C in the same table show the share of low carbon funds for different values of Morningstar's generic sustain-ability ratings (Globes) and overall financial performance ratings (Stars). High globes and high stars funds are more likely to receive the LCD. However, even among funds with one or two globes, or one or two Stars, a significant fraction obtained the low carbon eco-label.

Table A3 in the Supplementary Appendix explores the correlations of the new data with previously available firm-level environmental scores. It shows that the Portfolio Carbon Risk Score only mildly correlates with metrics investors may have self-computed, based on existing information (we calculated these measures based on portfolio holdings as of April 2018). In particular, the Portfolio Carbon Risk Score has a correlation of –0.27 with a port-folio's Sustainalytics' environmental score, –0.08 with a portfolio's Refinitiv's environmen-tal score, and –0.19 with a portfolio's MSCI–KLD's environmental score. Overall, the low correlation of the Portfolio Carbon Risk Score with prior environmental metrics confirms the relevance of the April 2018 information shocks.

Table I. Descriptive statistics

Descriptive statistics of active mutual funds domiciled in Europe and the USA for which infor-mation on Morningstar's LCD and flows is available. Panel A covers all fund-month observa-tions from April 2017 to September 2019, while Panel B is a snapshot from the end of April 2018. Panel C covers all fund-firm-month observations from April 2017 to September 2019. LCD is an indicator equal to 1 for funds that obtained the LCD label at the end of April 2018. CR and FFI are Morningstar's portfolio CR and FFI scores. Flows (in percentage points) is the monthly growth of assets, net of reinvested returns. Normalized flows is computed following Hartzmark and Sussman (2019). Return is the monthly net return. Log assets is the log of AUM, in USD. Volatility is the standard deviation of returns in the previous 12 months. Age is the number of years since the inception of the oldest share class. Globes is the Morningstar sustainability rat-ing, on a 1–5 scale. Stars is the Morningstar overall financial performance rating, on a 1–5 scale. DGlobes and DStars indicate if a fund received a downgrade (–1) or an upgrade (1) in the Morningstar Globes rating or Stars rating, respectively. Position change (in basis points) is the change in the number of shares held by fund f in stock i from month t–1 to month t, valued at the price of month t–1, divided by AUM in month t–1. Low CR (firm), Medium CR (firm), and High CR (firm) are indicators equal to 1 for firms with CR scores between 0 and 9.99 (low), be-tween 10 and 29.99 (medium), or above 29.99 (high), and 0 otherwise. FFI (firm) is an indicator equal to 1 for firms deriving a significant share of their revenues from fossil fuel-related activ-ities. Churn rate is a measure of how frequently fund managers rotate their positions on all the stocks in a portfolio. Position weight is the percentage of AUM invested in a firm.

Panel A: Fund-level variables, from April 2017 to September 2019

	N	Min	p25	Mean	p50	p75	Max	SD
LCD	379,086	0.00	0.00	0.18	0.00	0.00	1.00	0.39
CR	237,303	0.23	8.39	10.15	10.06	11.46	45.60	3.44
FFI	334,901	0.00	3.06	7.01	6.20	9.55	84.22	5.85
Flows	379,086	19.53	1.60	0.03	0.29	1.21	32.82	4.74
Normalized flows	379,086	1.00	27.00	49.38	49.00	72.00	100.00	27.24
Return	379,086	90.60	1.09	0.41	0.61	2.24	28.49	3.31
Log assets	379,086	13.82	16.82	18.40	18.35	19.86	26.02	2.06
Volatility	379,076	0.04	1.74	2.78	2.51	3.57	26.53	1.46
Age	379,086	1.00	6.26	14.01	12.65	18.89	119.32	10.12
Globes	275,778	1.00	2.00	3.05	3.00	4.00	5.00	1.13
Stars	237,315	1.00	2.00	3.15	3.00	4.00	5.00	1.06
DGlobes	379,086	1.00	0.00	0.00	0.00	0.00	1.00	0.32
DStars	379,086	1.00	0.00	0.00	0.00	0.00	1.00	0.30

Panel B: Fund-level variables, snapshot at the end of April 2018

	N	min	p25	Mean	p50	p75	Max	SD
LCD	13,056	0.00	0.00	0.18	0.00	0.00	1.00	0.39
CR	8,997	0.23	9.03	10.70	10.62	11.94	45.58	3.47
FFI	13,013	0.00	2.95	6.70	5.92	9.08	70.99	5.53
Flows	13,056	19.53	2.24	0.88	1.60	0.04	32.82	4.88
Normalized flows	13,056	1.00	26.00	48.80	47.00	71.00	100.00	27.44
Return	13,056	9.79	0.47	2.04	1.82	3.45	13.91	2.11
Log assets	13,056	13.86	16.84	18.42	18.36	19.89	25.93	2.05

(continued)

Table I. Continued

Panel B: Fund-level variables, snapshot at the end of April 2018

	N	min	p25	Mean	p50	p75	Max	SD
Volatility	13,056	0.12	1.73	2.24	2.30	2.72	8.65	0.80
Age	13,056	1.00	5.80	13.63	12.25	18.52	118.24	10.14
Globes	9,358	1.00	2.00	3.02	3.00	4.00	5.00	1.14
Stars	9,887	1.00	2.00	3.16	3.00	4.00	5.00	1.05

Panel C: Portfolio holdings

	N	min	p25	Mean	p50	p75	Max	SD
Position change	12,786,149	82.51	0.00	0.07	0.00	0.00	83.72	13.23
Position weight	12,398,436	0.00	0.06	0.78	0.33	1.11	46.20	1.10
CR (firm)	12,786,149	0.00	1.35	11.05	9.06	15.64	81.09	11.37
High CR (firm)	12,786,149	0.00	0.00	0.06	0.00	0.00	1.00	0.24
Medium CR (firm)	12,786,149	0.00	0.00	0.40	0.00	1.00	1.00	0.49
Low CR (firm)	12,786,149	0.00	0.00	0.54	1.00	1.00	1.00	0.50
FFI (firm)	12,786,149	0.00	0.00	0.10	0.00	0.00	1.00	0.30
Return (firm)	12,500,884		0.370.04	0.01	0.01	0.05	1.00	0.08
Volatility (firm)	9,737,999	2.65	5.43	7.20	6.62	8.31	39.07	2.72
Total buys (USDmm)	101,728	0.00	0.70	25.95	4.45	20.72	634.74	61.39
Total sells (USDmm)	101,461	0.00	0.75	27.08	4.73	21.91	654.85	62.81
Churn rate	101,728	0.00	0.03	0.09	0.06	0.11	6.19	0.12

2.2.b. Portfolio holdings data

From Morningstar On Demand, we obtain the monthly portfolio holdings from April 2017 to September 2019 of mutual funds (both from Europe and the USA) with available Portfolio Carbon Risk Scores. We keep only funds that report their holdings monthly and focus exclusively on their equity positions. We denote the number of shares held by fund f in stock i in month t as $\text{NumberShares}_{f;i;t}$.

To study fund managers' trading decisions, we compute the position change, expressed in basis points of AUM in the prior month, as

$$\text{Position change}_{i;f;t} = \frac{\text{Price}_{i,t} \quad _1\text{ðNumber Shares}_{f;i;t} \quad \text{Number Shares}_{f;i;t\ 1} \text{Þ} \quad 10^4}{\text{AUM}_{f;t\ 1}}$$

This variable is defined as in Gantchev, Giannetti, and Li (2022), for example. We trim position change at the 1st and 99th percentiles. Panel C of Table I reports the summary sta-tistics of the position changes and other portfolio firm-level variables. The median position change is zero, as fund managers keep most of their positions unchanged from 1 month to the next. For the non-zero position changes, that is, for actual trades, the median monthly position change is about 2.8 basis points. The median firm represents about 0.33% of a fund's portfolio.

The average portfolio firm has a firm-level carbon risk score of 11. Following the Sustainalytics (2018) methodology, we classify individual firms into three carbon risk rat-ings: low (carbon risk score between 0 and 9.99), medium (carbon risk score between 10 and 29.99), and high (carbon risk score above 29.99). We define the corresponding firm

indicators as low CR (firm), medium CR (firm), and high CR (firm). Similarly, we also consider the indicator FFI (firm) equal to 1 for firms deriving a significant share of their reve-nues from fossil fuel-related activities. On average, firms classified as having a high CR represent 6% of each portfolio, while firms involved in fossil fuel activities represent 10%.

The total buys and sells of the average fund in a given month are USD 26 million and USD 27 million, respectively, and the average churn rate is 0.09, meaning that about 5% of positions are turned over during a month.[9]

3. Conceptual Framework

In this section, we develop the conceptual framework that guides our empirical investiga-tions. We support this framework with descriptive analyses of funds' and their holdings' characteristics as of April 2018.[10]

Let us first briefly consider the role of carbon risk for individual securities. Several contributions in the literature indicate that green assets have insurance-like properties against climate risks (e.g., Engle et al., 2020; Bolton and Kacperczyk, 2021a; Ilhan, Sautner, and Vilkov, 2021; Ramelli et al., 2021b; Hsu, Li, and Tsou, 2022). In Figure 2, we confirm this to be the case using the firm-level carbon risk metrics published by Morningstar. Panel A shows the relation between a firm's carbon risk score and its return loading on negative climate-related news. For approximately 2,500 international firms covered by Sustainalytics, we regress each firm's monthly returns on the three Fama–French global factors and the stand-ardized news-based climate change risk index from Engle et al. (2020).[11] The estimated coeffi-cient Loading on negative climate news (firm) represents the firm-specific sensitivity to negative climate news (akin to a "climate beta"), net of the effect of the market, size, and value factors. Consistently with Engle et al. (2020), a firm's carbon risk relates negatively with the loading on negative climate news ($p < 0{:}001$), that is, low carbon risk firms outperform other firms in months with higher levels of negative climate-related news.

Panel B shows that firms with lower carbon risk also display lower average realized volatility. Indeed, Loading on negative climate news (firm) negatively relates to return vola-tility ($p < 0{:}001$) and explains approximately 2.75% of its variation.

How do the risk-management properties of low carbon firms translate to the fund level? The answer to this question is not obvious. While the expected return of a portfolio is sim-ply the weighted average of the expected returns of its individual holdings, the risk of a portfolio depends both on the variance of the individual securities and their covariances

9 This trading behavior is similar to that observed by Gaspar, Massa, and Matos (2005), who find that 20% of positions are turned over during one-quarter.

10 Table A4 in the Supplementary Appendix reports the summary statistics of the additional variables used in this section.

11 Engle et al. (2020) find that environmentally responsible firms—based on Sustainalytics' environ-mental scores—outperform non-environmentally responsible firms in months with more climate-related news. For our analysis, we use the negative news-based risk index the authors obtained from the data provider Crimson Hexagon (CH) ("CH Negative Climate Change News Index"), which focuses exclusively on negative climate news, and is available from January 2008 to May 2018. We thank Stefano Giglio and Johannes Stroebel for making these data available on their websites. We base our estimation on the period from January 2015 to April 2018, with a minimum of 12 monthly return observations, and we winsorize the estimated loadings at the 1st and 99th percentiles.

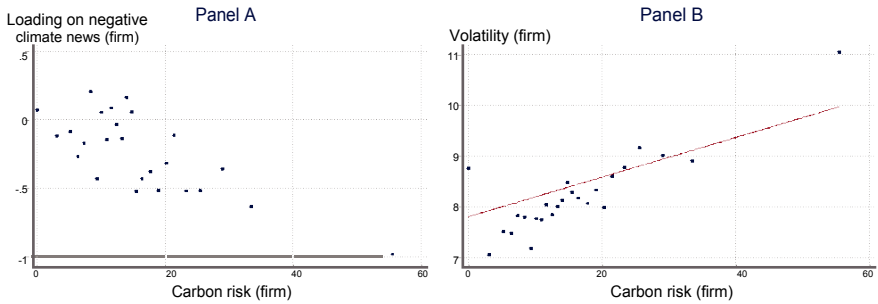

Figure 2. Low carbon firms are less risky. These graphs show binned scatterplots of firm-level loading on negative climate news (firm) and stock volatility, against firm-level carbon risk scores from Sustainalytics. Both graphs' plots employ twenty-five equal-sized bins (the maximum allowed, given the distribution of the x-axis variable). The sample includes 2,499 international firms for which Sustainalytics carbon metrics and stock prices from Compustat IQ are available. Loading on negative climate news (firm), used in Panel A, is the coefficient on the standardized negative news-based cli-mate risk index used in Engle et al. (2020) when regressing, for each stock with at least 12 monthly observations, the monthly returns from January 2015 to April 2018 on that index and on the three Fama–French global factors. Volatility (firm), used in Panel B, is the standard deviation of monthly returns over the same period.

(Markowitz, 1952). In Figure 3, we illustrate what this basic principle implies for the riski-ness of funds by analyzing the cross-section, as of April 2018, of 6,310 mutual funds with available 12-month average Portfolio Carbon Risk Scores. All graphs in Figure 3 are binned scatterplots employing thirty equal-sized bins.

Panel A shows that funds with lower scores hold, on average, less volatile firms. This re-sult follows intuitively from their tilt toward low carbon firms, which, as we noted above, are generally less risky, as well as being less exposed to climate-related risks.[12] However, as Panel B illustrates, the relation between fund-level carbon risk and portfolio volatility is not at all monotonic: Funds with lower levels of carbon risk hold less risky assets, but their overall portfolios are not less risky—and can even be riskier—than those near the market average, that is, close to a Portfolio Carbon Risk Score of 10.[13] (Recall that to qualify for the LCD eco-label requires a Portfolio Carbon Risk Score under 10.)

Why does this non-monotonic relationship arise? A candidate explanation is that low carbon funds hold assets with a high degree of covariance, which limits risk-sharing from a

12 Figure A2 in the Supplementary Appendix shows (again, in binned scatterplots with 30 equal-sized bins) that the portfolios of low carbon funds have, on average, less negative exposure to negative climate news; on the contrary, they tend to deliver higher returns under those conditions. This re-sult also follows naturally from the firm-level results in Figure 2 and confirms that low carbon funds provide investors with a better hedge against climate risks, as the portfolios constructed in Engle et al. (2020) and Alekseev et al. (2021) propose to do.

13 Regression results available on request confirm this graphical intuition. When regressing fund volatility on carbon risk for the sub-sample of funds with carbon risk scores above 10, we observe a positive relationship (0.07, $p < 0:001$): a lower carbon risk score is associated with lower fund volatility. However, for the sub-sample of funds with carbon risk scores below 10 (i.e., low carbon funds), the same relationship is negative (–0.02, $p < 0:001$): a lower carbon risk score is associ-ated with higher fund volatility.

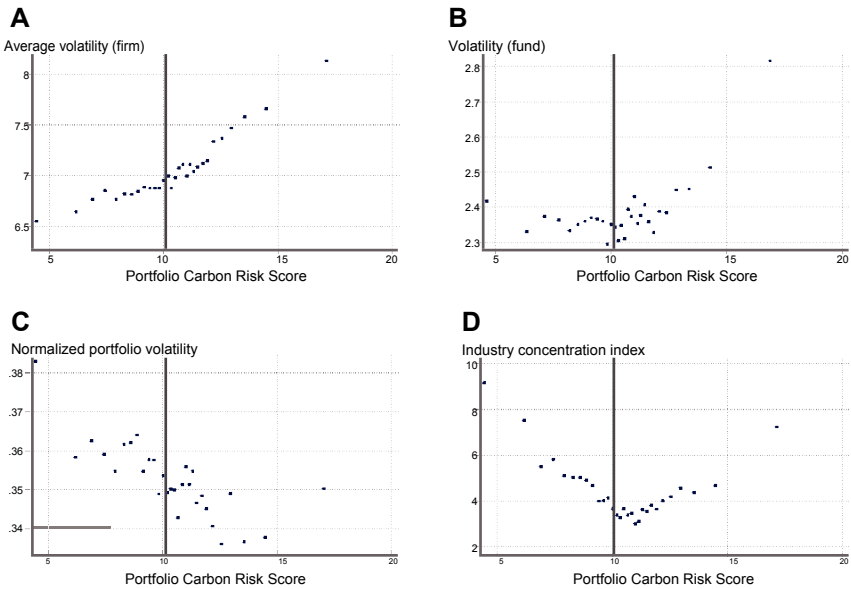

Figure 3. The trade-off of low carbon funds. These graphs show binned scatterplots of fund-level aver-age volatility (firm) (A), volatility (fund) (B), normalized portfolio volatility (C), and industry concentra-tion index (D), all against fund-level 12-month-average portfolio carbon risk scores. All graphs employ thirty equal-sized bins. The sample includes 6,310 US and European funds with available carbon risk scores, fund flows, and individual portfolio holdings data as of April 2018. All graphs control for fund size and category fixed effects. The solid vertical lines indicate the carbon risk score threshold for a fund to be labeled "low carbon" by Morningstar. Average volatility (firm) is the asset-weighted aver-age volatility of a fund's individual equity holdings. Volatility (fund) is the standard deviation of port-folio monthly returns from December 2016 to April 2018, with at least twelve available observations. Normalized portfolio volatility is the ratio of the portfolio volatility over the asset-weighted average volatility of individual equity holdings. Industry concentration index is the sum of the squared devi-ation of a fund's GICS group industry weights, relative to the global equity market portfolio.

mean–variance perspective. We probe this interpretation by considering two measures of portfolio diversification. Normalized portfolio volatility, proposed by Goetzmann and Kumar (2008), is computed by dividing a portfolio's total volatility by the average volatility of the individual stocks it contains. The higher this measure, the more unexploited opportu-nities exist to diversify the portfolio and reduce its volatility. Panel C in Figure 3 shows that low carbon funds have a relatively high normalized portfolio volatility.

The second measure we employ, the Industry concentration index proposed by Kacperczyk, Sialm, and Zheng (2005), is computed as the sum of the squared deviations of a fund's GICS industry weights, relative to the industry weights of the global equity market portfolio. Panel D in Figure 3 displays the relationship between funds' carbon risk and indus-try concentration, controlling for fund size and category. The resulting U-shaped curve con-firms that the volatility of low carbon funds reflects significantly less sectoral diversification.[14]

14 This result holds when we match our dataset with data from Pa´ stor, Stambaugh, and Taylor (2020a), producing a sample of 915 US domestic equity mutual funds with available diversification data for 2014. Our results (available on request) show that funds classified as low carbon in April

To probe the quantitative importance of industry concentration, we run OLS regressions of fund volatility on quintile category indicators of Portfolio Carbon Risk Score, as shown in Table II. In Column 1, we observe that funds in the bottom quintile of carbon risk—that is, low carbon funds—exhibit significantly higher portfolio volatility than do median car-bon risk funds. (As is to be expected, funds in the top quintiles of carbon risk also have higher volatility than do median funds.) However, when we control for the funds' industry concentration (Column 2), the volatility difference between bottom quintile and median carbon risk funds becomes statistically insignificant and even turns slightly negative (– 0.01). In this specification, the relationship between fund volatility and carbon risk is simi-lar to that observed at the individual security level (Figure 2, Panel B).

In Columns 3 and 4, we also account for the funds' number of holdings (linearly, and also in quadratic form, due to the non-linear relationship between volatility and the number of holdings), which reduces the coefficient on the first quintile of carbon risk further, but only mildly. Based on these estimates, industry concentration appears to account for around 75% of the extra higher volatility of bottom-quintile-carbon-risk funds, while the number of holdings accounts for the remaining 25%.[15]

The industry imbalance of low carbon funds is also visible in their portfolio composition. Figure 4 provides descriptive evidence on the composition of low carbon funds by GICS industry groups. As expected, these funds overweight IT, retail, and healthcare firms, while they underweight energy, materials, and utility firms. Figure A1 in the Supplementary Appendix shows that low carbon funds have a geographical exposure similar to that of other funds. We also observe no substantial differences in terms of exposure to the market or size factors. However, as may be expected, low carbon funds have lower exposure to the value factor, given their significant overweighting of growth sectors, a fact consistent with the observation in Pa´stor, Stambaugh, and Taylor (2020a) that green securities tend to be growth-oriented.

Overall, these analyses illustrate the fundamental trade-off investors and fund managers face: On the one hand, by overweighting green securities, they reduce their exposure to cli-mate risks. On the other hand, by moving away from the status quo in our not-yet-low car-bon world, they miss opportunities to diversify.

Studying how investors and fund managers behave when confronted with this trade-off is crucial to understanding the role of financial markets in the energy transition. However, this task is complicated by several empirical challenges. Investors with different preferences tend to self-select into different types of funds. Similarly, fund managers' decisions are driven by many forward-looking considerations, making it difficult to isolate the effect of one specific firm characteristic on their trading behavior. We address these challenges by studying the reactions of mutual fund clients and managers to the introduction of

2018 have a statistically significant lower "balance," that is, the resemblance of firm-level port-folio weights relative to market cap weights, even after controlling for category fixed effects. We thank Lucian Taylor for making these data available on his website.

15 When we control for industry concentration, the coefficient of 0.05 on the 1st quintile CR in Column 1 is reduced to 0.01 in Column 2, that is, by 0.06. When we add a linear and squared term for the number of holdings, it falls by another 0.02 to 0.03 in Column 3, for a total difference of 0.08. Therefore, 75% (0.06/0.08) of the unusually high volatility of funds in the first quintile of car-bon risk is explained by their high industry concentration, whereas 25% (0.02/0.08) is explained by the number of their holdings. The fact that low carbon funds' higher volatility does not strongly de-pend on the number of their holdings confirms that it reflects a higher average asset covariance and cannot be reduced simply by bundling many low carbon mutual funds (Markowitz, 1976).