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Do Sustainable Investment Strategies Hedge Climate Change Risks? Evidence from Germany's Carbon Tax

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Abstract

It is difficult to assess the effectiveness of investment strategies that screen companies based on environmental criteria to hedge climate change risk because physical risks have not yet fully materialized and policies to combat climate change are usually widely anticipated. This paper sidesteps these limitations by analyzing the stock market response to plausibly exogenous changes in expectations about the level of a carbon tax in Germany. The risk-adjusted return on two sustainable investment approaches—screening companies based on environmental scores and on firms' carbon footprint—around the carbon tax news reveals that firms with a high environmental score did not perform any better than those with a low environmental score. In contrast, the stock price of firms with low carbon emissions increased in value relative to those with a high carbon footprint. Carbon intensity explains the cross-sectional reaction to the carbon tax news because it predicts revisions in expected profitability.

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1 Introduction

There is increasing scientific consensus that, as carbon dioxide (CO_2) emissions and global temperatures continue their upward trajectory, the potential risks from climate change are substantial. Indeed, the scientific evidence on the potential physical risks from climate change shows that the frequency and severity of extreme weather events and natural disasters—such as heat waves, droughts, floods, wildfires—are likely to increase with CO_2 emissions and that temperature increases can reduce economic growth (see the evidence in Dell, Jones, and Olken (2012), and Colacito, Hoffmann, and Phan (2019)). Mitigating the adverse effects of climate change requires substantial cuts to greenhouse emissions, which could be achieved by implementing policies that promote the transition from carbon-intensive activities to low-emission alternatives.[1]

Investors are beginning to recognize that climate change, and the policy responses to it, could pose a risk to their investments. It is no surprise that investment strategies that screen companies based on some environmental criteria have grown dramatically over the past years.[2] Indeed, the practice of investing in companies or funds that aim to achieve market-rate financial returns, while considering positive social or environmental impact, is gaining more popularity among institutional investors. Among asset owners surveyed by Morgan Stanley, 80% said that they actively integrated sustainable investing in 2019, up 10 percentage points from the 2017 survey (see, Morgan Stanley's 2019 survey). This trend reflects both a shift in preferences toward investment opportunities that would help contain the climate crisis and a growing concern about the risks from climate change, particularly those from policy responses to speed up the transition to a carbon neutral economy—namely, transition risks.

There is, however, no systematic empirical evidence that investing in companies

[1]The most recent Intergovernmental Panel on Climate Change (IPCC) report asserts that near-term actions that limit global warming could avert the projected catastrophic damages from climate change in human systems and ecosystem. For more details, see IPCC, 2022: "Climate Change 2022: Impacts, Adaptation, and Vulnerability." Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

[2]In 2020, about $17 trillion—roughly one-third of all assets under professional management in the U.S.—were being managed using some type of sustainable-investment strategy, according to the US SIF Foundation 2020 Report on US Sustainable and Impact Investing Trends.

with high environmental ratings or in sustainable-themed products is a good climate risk-hedging strategy because physical risks from climate change have not yet fully materialized, and policies to combat climate change are usually widely anticipated by the time they are signed into law. In this paper, we sidestep these limitations by analyzing the performance of simple dynamic investment strategies intended to hedge climate change risks around a likely exogenous change in expectations about the level of a carbon tax. Our analyses exploit the events leading to the approval of the German carbon pricing system for the transport and buildings sectors in December of 2019. The passage of this legislation presents a unique quasi-natural experiment for studying the hedging properties of common investment strategies used by environmentally minded investors. For one thing, after a last-minute round of negotiations, the climate law set a CO_2 price at €25 (about US$ 27) per ton of carbon, which was more than double than the initially planned carbon tax of €10 (about US$ 11). German legislators also agreed to steeper increases in the carbon tax over the next years. Both of these actions came as surprises to financial markets. [3] Furthermore, the increase may have also signaled the government's commitment to strong implementation of future climate policies in Germany.[4] These qualities could lead to substantial cross-firm heterogeneity in the reaction to the carbon tax news and make this event well suited to an event study.

Our analysis exploits the unexpected increase in the carbon tax to assess the performance of two dynamic investing strategies that are commonly used by investors in equity markets to hedge climate risks. First, we consider a strategy that integrates a firm's environmental pillar of the environmental, social, and governance (ESG) score to rank and remove or underweight stocks with a low environmental score in a portfolio. The second approach relies on using information about corporate CO_2 emissions to reduce the carbon footprint of an investor's portfolio. Krueger, Sautner, and Starks

[3]The increase in the carbon tax was a surprise not only to financial market participants but also to experts in German climate policy. See, for example, the interview to the Secretary General of the Mercator Research Institute on Global Commons and Climate Change based in Berlin: Klimaschützer haben sich gegen Bremser durchgesetzt.

[4]For press coverage of the event, see, for example, Bloomberg, December 16, 2019, "Germans Agree CO_2 Taxes Aren't High Enough and Want to Pay More".

(2020) report that, among institutional investors, ESG integration and analysis of carbon footprints are among the top risk management tools used hedge against climate risks as investors consider that these variables capture a firm's exposure to climate change risks. Using a sample of German companies listed at the Frankfurt Stock Exchange that either report CO_2 emissions or have emissions estimated from energy use, we investigate the effect of the news about an agreement to raise the carbon tax on the market value of investment strategies that rely on a firm's environmental score or CO_2 emissions. We conduct our analyses of the stock market performance of these investment strategies over the following event windows: the immediate reaction to the news about the carbon tax agreement, December 16 (Monday, 1-day window); the time between the news and the passage of the climate package, including the steeper carbon tax, in the lower house of Parliament, December 16 to December 18 (3-day window); and the time between the news and the passage of the climate package in the upper house of Parliament, December 16 to December 20 (5-day window). Our main identification assumption is that the carbon tax news was both largely unexpected and the likely the main event driving asset prices around the time when the news of the carbon tax increase was reported.

We use two complementary approaches to assess the effect of unexpected news about the carbon tax. We begin by constructing portfolios ranked by either a firm's environmental score or a firm's CO_2 emissions and examine the response of the risk-adjusted stock returns on these portfolios to the higher-than-expected carbon tax.[5] If these dynamic investing strategies are a good hedge against climate risks, an investor would expect that, in response to the announcement of a higher-than-expected carbon tax, a portfolio of stocks with a low environmental score or with a high carbon footprint would decline in value relative to a portfolio of stocks with a high environmental score or low levels of CO_2 emissions.

Our portfolio analysis shows that there is little evidence that holding a portfolio

[5]Using a factor pricing model, we isolate the portion of risk that cannot be fully diversified and that is explained by known risk factors likely unrelated to climate policy risk. We use estimated firm-level exposures to broad market moves (CAPM model) as well as to the Fama and French (1995) size and value factors to compute risk-adjusted returns.

with stocks at the top of the environmental score distribution hedges the realization of climate policy risks. We find that, around the carbon tax news, the risk-adjusted return on a portfolio of stocks with the highest environmental rating—A- or higher—was not statistically different from a portfolio of stocks at the bottom of the rating distribution—C+ or lower. In contrast, we document that strategies that screen companies based on their CO_2 emissions are likely to produce a good hedge to realizations of climate policy risk. We find strong evidence of a negative relationship between the stock market response to the carbon tax news and a portfolio's CO_2 intensity as captured by the ratio of CO_2 emissions to the total value of assets. A strategy that is long a portfolio with low CO_2 intensity firms and short a portfolio with high CO_2 intensity firms produces a positive risk-adjusted return of around 1.3% the day of the carbon tax news, around four-fifths of a standard deviation of risk-adjusted returns realized over the same event window. Interestingly, the spread in risk-adjusted returns between low and high CO_2 intensity portfolios remains positive and increases modestly as we expand the event window to include the subsequent votes in Parliament demonstrating that the relative gains in value of portfolios with a low carbon footprint were persistent and the results are robust to substantial variations in the event study window.

Next, we use firm-level information on stock prices to perform cross-sectional regressions and assess the response of stock prices along the two dimensions—environmental scores and CO_2 emissions—used by environmentally minded investors to hedge climate risks. The advantage of cross-sectional regressions over sorting stocks into portfolios is that by using firm-level observations it provides more efficient estimates of a firm's risk exposure. At the same time, it allows us to control for potential observable firm-level characteristics unrelated to a firm's exposure to climate change but that could explain the moves of stock prices over the event window, including industry effects. The results show that a firm's environmental score cannot explain the change in the firm's market value around the carbon tax news, which calls into question the view that environmental scores capture a firm's exposure to risks from climate change. The inability of environmental scores to predict the response in equity

prices to the carbon tax news does not seem to stem from the potential presence of measurement error in scores (Berg, Kölbel, Pavlova, and Rigobon, 2021). We show that the stock price reaction to carbon tax news is essentially uncorrelated with a firm's environmental score for the largest German firms in our sample—which have scores measured with a higher precision than the overall sample because these firms provide high quality inputs that rating agencies use to compute the scores—and for estimates suing the scores from three additional data providers.

While the stock price of firms with a high environmental score did not perform any better than the stock price of a firm with a low environmental score, we find that a firm's CO_2 intensity—the ratio of CO_2 emissions to the total value of assets—is a robust predictor of the reaction of stock prices to the carbon tax news. Our estimates suggest that a one standard deviation decline in CO_2 intensity is associated with an increase in the risk-adjusted equity value of 0.3 percentage points—around a one-fifth of the standard deviation of risk-adjusted returns over this window. We also show that the estimated coefficient on CO_2 intensity increases when we expand the event window to capture the carbon tax approval in the lower and upper houses of the German Parliament, suggesting that the unexpected increase in the carbon tax also conveyed new information about the likelihood of and risk from further policies aimed at reducing carbon emissions in Germany.

What explains the success of carbon intensity in explaining the cross-sectional reaction in equity values to the carbon tax news? We show that CO_2 intensity explains much of the cross-sectional reaction to the carbon tax news because carbon intensity predicts revisions in expected profitability after the unexpected carbon tax news. In particular, using information from analysts' earnings forecasts over the next two years, we find that equity analysts' revised down significantly the earnings forecasts of firms with a high CO_2 intensity relative to their counterparts with a lower CO_2 intensity, suggesting that the reaction of stock prices over the event window reflects, to some extent, revisions in the expected profitability of firms in response to climate policy news. We also show that analysts marked down their forecast for long-term growth in earnings, suggesting that the carbon tax announcement changed not

only analysts' expectations of firms' level of earnings but also their growth trajectory.

Our study is related to a recent but growing literature studying the implications of climate change risks for sustainable investing. Engle, Giglio, Kelly, Lee, and Stroebel (2020), for example, proposes using a portfolio that mimics fluctuations in news about climate change from leading news outlets to hedge climate risks. Alekseev, Giglio, Maingi, Selgrad, and Stroebel (2022) uses changes in stock holdings from mutual fund managers experiencing unusually high temperatures to identify stocks that are exposed to climate change risks. Our empirical evidence highlights the value of using a simple measure of climate risk exposure—a firm's carbon footprint—to dynamically hedge risk from policies intended to reduce carbon emissions, and the risk of relying on environmental scores to identify exposure to climate change.

Our results are also informative for the literature studying the theoretical implications of climate risks for portfolio allocation. Heinkel, Kraus, and Zechner (2001), for example, explore the implications of exclusionary ethical investing on equity prices. More recently, Roth Tran (2019) studies the trade-offs that a philanthropic foundation faces when deciding how much to invest in a firm whose activities might be considered objectionable, including, for example, foundations concerned about climate change investing in fossil fuel stocks. In a model featuring environmentally minded investors, Pástor, Stambaugh, and Taylor (2021) and Pedersen, Fitzgibbons, and Pomorski (2021), show that stocks with a high environmental score—*green* stocks—have lower expected returns than those environmentally unfriendly—*brown* stocks. Our empirical evidence points to carbon emissions as a relevant and informative firm characteristic to test the implications of these models.

Our study builds and extends the literature employing an event study methodology to evaluate the effects of changes in climate policy through the lenses of financial markets. Ramelli, Wagner, Zeckhauser, and Ziegler (2021) uses the reaction of stock prices to the results of the U.S. 2016 and 2020 Presidential elections to explore the effects of shifts in expectations about climate policy on financial markets. Similarly, Meng (2017) uses an event study methodology around the failed attempt to pass the

Waxman-Markey bill—a cap-and-trade climate policy—in the U.S. Senate.[6]

Finally, our paper contributes to the literature asking whether financial markets reflect the potential risks from climate change. The equity market is studied in, for example, Bansal, Kiku, and Ochoa (2019), Bolton and Kacperczyk (2021), Pástor, Stambaugh, and Taylor (2022); the corporate bond market is explored in Huynh and Xia (2021), Caramichael and Rapp (2022), Duan, Li, and Wen (2021); the municipal bond market is studied in Painter (2020), Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2021); and the options market in Kruttli, Tran, and Watugala (2019), Ilhan, Sautner, and Vilkov (2021). Our paper complements these studies by documenting the impacts of policies that lead the economy to a low carbon transition through the lenses of financial markets.

The remainder of the paper is organized as follows. In section 2, we detail our empirical approach, as well as the events around the carbon tax negotiations, and describe the data. Section 3 uses the reaction of stock prices to the unexpected carbon tax increase to assess the climate-hedging properties of two dynamic investing strategies. Section 4 uses earnings forecasts to shed some light on the reasons behind the success of carbon intensity in explaining the cross-sectional reaction in equity values to the carbon tax news. Section 5 section concludes. The Appendix presents additional results to examine the robustness of our empirical evidence.

2 Methodology and Data

2.1 Sustainable Investment Strategies

Investors in equity markets are increasingly turning to information about a firm's carbon footprint as well as to environmental, social, and governance (ESG) scores to design investment strategies that allow them to hedge the physical and transition risks from climate change. Our focus is on two investment strategies that integrate

[6]Our paper also adds to the literature using the high-frequency response of asset prices to explore the impacts of policy changes. Cutler (1988) explores the impact of changes in tax policy, and Snowberg, Wolfers, and Zitzewitz (2007) evaluates the effects of election outcomes on the economy.

ESG scores or carbon emissions data directly into the security selection process. First, a currently popular strategy uses the Environmental pillar of the ESG score—the environmental score—to rank companies and remove or underweight stocks with a low environmental score. The recently created S&P 500 ESG Index, for example, uses proprietary ESG scores to define the weight in the index of a large set of companies included in the original S&P 500 Index. The underlying assumption behind this strategy is that the environmental score is a good proxy for a firm's exposure to climate risk, which allows investors build portfolios resilient to climate risks and, at the same time, produce better long-term, risk-adjusted returns.[7]

Second, as a growing number of companies are disclosing their greenhouse gas emissions following widely accepted standards,[8] investors are increasingly using this information to trim the carbon footprint of their portfolios and produce fully or partially "decarbonized" portfolios by underweighting or excluding stocks with relatively high carbon emissions. Indeed, Krueger et al. (2020) report that, among institutional investors, the most frequently risk management approach to hedge against climate risks relies on the analysis of firms' carbon footprints. This approach implicitly assumes that corporate CO_2 emissions capture a firm's exposure to climate change risks.

While a company's environmental pillar score takes into account information on CO_2 emissions, the environmental score also reflects other areas of environmental friendliness such as resource use and green innovation, which in many industries have a much bigger influence than CO_2 emissions on a company's environmental ranking.[9] As a result, investors rely on the environmental score to assess a company's efforts in environmental issues beyond those that are linked to current carbon emissions — for example, the environmental score may include a firm's plans to achieve carbon neu-

[7]About 80% of respondents to Morgan Stanley's 2019 survey of investors said that they actively integrate ESG factors into the investment process, and 15% are already considering doing so. The growing interest in ESG investing reflects the view that 78% of investors responding to the same survey see financial return potential.

[8]Companies and data providers use the standards set by the Greenhouse Gas Protocol to measure and report carbon emissions.

[9]Most industries have a weight of about one-third on emissions in the environmental score—for example, the transportation industry has an emissions weight of 0.29, utilities have an emissions weight of 0.43, and the durable goods industry has a weight of 0.35. Overall, the weight on emissions in the environmental score ranges from 0.46 to 0.22, with the weight on emissions declining with the carbon intensity of industries.

trality over the medium term, so it is considered, to some extent, as a forward-looking measure of a firm's environmental friendliness. Both the environmental score and carbon emissions are used in the literature and by investors to capture a company's exposure to climate change risks.

2.2 Expectations of Carbon Tax Changes: the Case of Germany

In September of 2019, Germany's Chancellor Angela Merkel introduced a climate policy package that included a national pricing system for carbon emissions in the transport and building sectors. The package proposed a starting carbon tax of €10 (about US$11) per ton of CO_2 in 2021 and planned a gradual increase over the next five years, reaching to 35 euros (about US$40) per ton of CO_2 in 2025. After the climate package was introduced, climate scientists and members of Germany's Green Party criticized the €10 carbon tax on transport and heating as too low to effectively reduce carbon emissions from these sectors. Chancellor Angela Merkel's government, however, saw a low initial carbon price as necessary to secure public support.

On November 15, the proposed pricing system for CO_2 emissions from transport and heating was approved by the German lower house of Parliament, and it was expected to pass the upper house in late 2019. Other parts of the government's climate package of which the carbon pricing scheme was an element required a mediation agreement between the two chambers due to impacts on state tax revenues. The domestic carbon pricing scheme was not reportedly under negotiation. After debating all the weekend of December 14 and 15, however, lawmakers agreed to raise the 2021 initial carbon tax from €10 per ton of carbon to €25 per ton of carbon, and a steeper increase in the carbon tax over the next five years. Monday's headlines reported "Germans Agree CO_2 Taxes Aren't High Enough and Want to Pay More," and news coverage described the debate as "grueling" and a "hard-fought compromise" that "broke a parliamentary deadlock."[10] It is possible that financial markets anticipated a compromise on

[10] For more details, see Bloomberg, December 16, 2019, "Germans Agree CO_2 Taxes Aren't High Enough and Want to Pay More," Phys.org, December 16, 2019, "Germany Agrees to CO_2 Pricing Deal After Grueling Debate."

the carbon tax level. For one thing, the Green Party criticized the tax of €10 per ton of carbon and climate activists felt that a €40 per ton of carbon was more appropriate. However, meeting environmental advocates' desired €40 per ton of carbon halfway was more than double the initial carbon tax level, so the negotiations could have easily settled on a much lower carbon tax. In fact, climate policy advocates expressed surprise at the ultimate increase in the carbon level on the day the news broke. [11]

The events around the passage of this legislation present a unique quasi-natural experiment for assessing the hedging properties of sustainable investment strategies. Our identifying assumption is that the carbon tax news was both largely unexpected and the main shock driving asset prices around December 16 and is therefore well suited to an event study. Moreover, setting a higher CO_2 price—though targeted to specific sectors—might have also signaled an increased likelihood of further policies aimed at reducing carbon emissions in Germany. If so, we would expect cross-firm heterogeneity in the reaction to the carbon tax news, beyond the sectors targeted by the carbon tax of the climate policy package.

2.3 Methodology

We use two complementary approaches to assess the effect of unexpected news about the carbon tax on the market value of investment strategies that screen companies based on some environmental criteria as described in Section 2.1. One, we form portfolios ranked by either a firm's environmental score or a firm's carbon emissions, which are used by investors to proxy for a firm's exposure to climate change risks. If these dynamic investing strategies are a good hedge against climate risks, investors would expect that in response to the higher-than-expected carbon tax, portfolios with a low environmental score or high carbon footprint would decline in value more than

[11] For example, Dr. Knopf, the Secretary General of the Mercator Research Institute on Global Commons and Climate Change based in Berlin, who co-authored the MCC report on options for a carbon pricing reform in Germany that was presented to the Climate Cabinet expressed, "Yes, I was surprised that the measures that had been decided on were improved at all. I hadn't expected that, despite the strong protests against the original government decision on the climate package in September," said in an interview when asked if the result surprised her. See, Spiegel, December 16, 2019, Klimaschützer haben sich gegen Bremser durchgesetzt.

those with higher environmental scores or with a lower carbon footprint.

Two, using firm-level observations, we model stock returns around the carbon tax vote as a function of a firm's environmental score—or CO_2 emissions—and financial characteristics,

$$AR_\tau^i = \phi_0 + \phi_1 \mathrm{E}_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}_{t-1}^i + \varepsilon_t^i \tag{1}$$

where AR_τ^i is the risk-adjusted cumulative stock return from the day or days around the carbon tax vote, E_{t-1} is either the environmental score of firm i or the firm i's CO_2 emissions reported for the fiscal year before the event period τ. The vector $\boldsymbol{x}_{t-1}^i$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization ($\ln$ MKTCAP); (log) price-to-book value ratio ($\ln$ PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). Finally, all regressions include industry fixed-effects for the following industry groups: consumer nondurable and durable goods; manufacturing, and mining; oil, utilities, and transportation; and services, which are categorized according to the Fama-French industry classification.[12] These control variables capture the exposure of firms to other macroeconomic shocks unrelated to climate risks that could bias the estimates of the slope coefficient ϕ_1.

Each method, sorting stocks into portfolios and cross-sectional regressions, have its own advantages and are, in turn, complementary. Portfolio sorts do not assume a linear relationship and, in situations when the relationship between returns and the firm characteristic is unknown, portfolios are robust to misspecification. In fact, portfolio sorts can be interpreted as a nonparametric cross-sectional regression (see, Cochrane, 2011). Cross-sectional regressions, however, make use of the full data providing more efficient estimates of a firm's risk exposure. In addition, cross-sectional regressions allow to control for firm-level characteristics that are known to explain the exposure of stock prices to risks that are likely unrelated to climate change. We rely on the complementary evidence from both approaches—portfolio sorts as well as cross-

[12]We construct five industry groups grouping the 17 industry definitions from Kenneth French's website.

sectional regressions—to assess the performance of the two sustainable investment strategies around the carbon tax news to mitigate concerns that any shortcomings associated with one of these approaches are influencing our conclusions.

Our analyses assess the performance of the characteristic-sorted portfolio and obtain the estimates of the cross-sectional regression (1) over the following event windows: the immediate reaction to the carbon tax news, December 16 (Monday, 1-day window); the time between the news and the passage of the climate package, including the steeper carbon tax, in the lower house of Parliament, December 16 to December 18 (3-day window); and the time between the news and the passage of the climate package in the upper house of Parliament, December 16 to December 20 (5-day window).

2.4 Measuring Risk-adjusted Returns

To isolate the portion of risk that cannot be fully diversified and that is explained by known risk factors—likely unrelated to climate risks—driving movements in equity prices, our empirical analysis uses a factor pricing model to obtain a measure of firm-level risk-adjusted returns, namely,

$$R_t^i = \alpha_i + \boldsymbol{\beta}_i' f_t + AR_t^i, \tag{2}$$

where R_t^i is the return on stock i in excess of the risk-free rate, f_t is a vector of factors capturing aggregate risk. The coefficient $\boldsymbol{\beta}_i$ captures the exposure of firm i to aggregate risks embedded in f_t that cannot be fully diversified. The risk-adjusted return is then the residual $AR_t^i = R_t^i - \alpha_i - \boldsymbol{\beta}_i' f_t$. Our empirical exercise uses two sets of factors to obtain risk-adjusted returns. First, in the spirit of the CAPM model of Sharpe (1964) and Lintner (1965), we use the return on the market portfolio in excess of the risk-free rate as the factor explaining expected returns and denote the abnormal returns as CAPM-adjusted returns. Second, we use the three-factor model of Fama and French (1996) and let f be a vector with the excess return on the market portfolio, the return on a portfolio of small firms in excess of the return on a portfolio of large stocks (SMB, small minus big), and the return on high book-to-market stocks minus the return on

low book-to-market stocks (HML, high minus low). We denote the abnormal returns from this specification as Fama French-adjusted returns.

Using risk-adjusted returns allow us to control for known differences in risk and characteristics of stocks that are likely unrelated to the exposure of stocks to transition risks from climate change. The three factors of Fama and French (1996), for example, have been shown to control for dimensions of risk observed in portfolios formed on earnings-to-price, cash flows-to-price, sales growth, and reversals, which are unlikely to be linked to risks from climate change (see, for example, Fama and French, 1995). At the same time, Bansal et al. (2019) document that high book-to-market portfolios are negatively exposed to temperature shocks, although the estimated risk premium is relatively small. This evidence suggests that controlling for the HML factor might lead to understate the "true" impact of carbon tax news on stock returns. On the other hand, climate-related risks are unlikely to be the key drivers of SMB and HML factors. Controlling for risks embedded in these variables, in turn, likely reduces the noise in stock returns unrelated to the carbon tax news, improving the identification of the impact of transition risks within the event study window.

We estimate the factor model's coefficients α_i and β_i for each firm using a 1-year sample of daily data between December 1, 2018 and December 1, 2019. We then use the estimated factor exposures β_i along with the estimated factor returns around the event-study windows to compute risk-adjusted returns. Note that we also subtract α_i to control for differences in average returns over the year preceding the carbon tax news that could emerge from a surge in demand for particular stocks. In particular, adjusting for α_i would likely capture the potential rise in value of stocks with high environmental scores or low carbon emissions due to increased investor preference for environmentally friendly stocks before the carbon tax event.[13]

[13] In, Park, and Monk (2019), for example, shows that stocks of U.S. companies with low carbon emissions outperformed over the 2005-2015 period, earning, on average, an abnormal return of 3.5%–5.4% per year relative to high CO_2 emissions stocks.

2.5 Data and Summary Statistics

Our sample consists of German firms listed on the Frankfurt Stock Exchange that are part of the Prime Standard segment.[14] For these group of firms, we collect firm-level environmental scores—the environmental sub-score of the ESG score—provided by Refinitiv. These scores are assigned as letter grades, which we convert to a numeric scale between 0 and 1 using Refinitiv's grading rubric. We also collect the Carbon Disclosure Project climate change score, RobecoSAM environmental score (obtained from Eikon), and S&P IQ environmental score. For our analyses, we mostly rely on Refinitiv's environmental score as it covers a larger number of publicly traded German firms and use the scores from the other data providers to mitigate the concern that our findings might depend heavily on the data provider we select.

We also obtain CO_2 emissions from Refinitiv, which are grouped in three different categories: scope 1 emissions, which are direct emissions from the firm's production; scope 2 emissions, which are the result from the generation of purchased energy; and scope 3 emissions, which are downstream emissions from product use from customers.[15] We focus our analysis on scope 1 and scope 2 emissions because there are widely used greenhouse gas accounting standards that standardizes how corporations measure and report scope 1 and scope 2 emissions. Bolton and Kacperczyk (2021), for example, shows that the correlation of scope 1 and scope 2 CO_2 emissions among five data providers is very close to 1. In contrast, scope 3 emissions are rarely reported and their estimates, as noted in Busch, Johnson, and Pioch (2022) and Bolton and Kacperczyk (2021), are usually inconsistent across different data providers. The analyses in this paper are based on environmental scores and CO_2 emissions reported for the fiscal year 2018, which are known to investors by the time when the carbon tax event occurred.

The following financial characteristics of firms in our sample are obtained from

[14]The Prime Standard is a segment of the stock market that meets the highest European transparency requirements. Firms part of this segment, for example, are required to produce quarterly financial reports, hold at least one analyst conference per year, and apply international accounting standards. The constituents of the broad stock market indexes widely followed by investors, such as the DAX, MDAX or SDAX, are Prime Standard.

[15]These categories follow the guidelines in the Greenhouse Gas Protocol

Refinitiv for the fiscal year 2018: market capitalization, book-to-market equity ratio, ratio of annual income to market equity. In addition, we collect information about a firm's participation in the EU ETS. In a few cases, when the financial data for 2018 was missing, we use data for the 2017 fiscal year. We also collect the NAICS industry code for each firm to construct the industry dummy variables.

The daily stock returns at the firm level are computed from daily individual stock prices obtained from Refinitiv. To obtain risk-adjusted stock returns, as described in Section 2.4, we use the daily return on the CDAX index[16] as a proxy for the market return and the German sovereign yield on a 1-month security as a proxy for the risk-free rate, both series come from Haver Analytics. We also collect the three factors of Fama and French (1996)—MKT, SMB, and HML—for portfolios on European stocks from Kenneth French's Data Library, which we convert to local currency using the spot USD/EUR exchange rate obtained from Bloomberg. We use one year of daily data prior to the carbon tax news to compute each stock's CAPM-adjusted and Fama French-adjusted returns using the factor model (2). Consequently, our daily stock market data covers December 1, of 2018 to December 20, 2019.

To select the sample of firms in our analyses, we begin by restricting our sample to firms that report CO_2 scope 1 and 2 emissions or whose emissions are estimated by Refinitiv using a firm's energy use. [17] Next, we restrict the firms in our sample to those that have been traded in the stock exchange for at least one year before the carbon tax news. Finally, we drop from our sample companies whose stock prices are below €5 per share at the beginning of our sample, namely, those that are considered a penny stock.

Our final sample consists of 115 unique companies. Table 1 provides summary statistics for various measures of carbon emissions, firm financial characteristics, and

[16]The CDAX is a German stock market index that captures the performance of all stocks traded on the Frankfurt Stock Exchange that are in the Prime Standard and General Standard segment.

[17]When reported emissions are not available, Refinitiv estimates emissions using one of three methods: the firm's carbon emissions from the previous year, emissions estimated from energy use, or the median carbon emissions for the firm's industry. We exclude 54 firms from our sample for not reporting emissions or having emissions estimated using the industry median emissions or previous years emissions. The firms that do not report CO_2 emissions and instead have emissions estimated tend to be small—as captured by their market capitalization—and have a low environmental score.

stock returns around the carbon tax news. In terms of environmental variables, the carbon footprint of the firms in our sample, captured either by CO_2 emissions or carbon intensity, shows important variation. The average firm in our sample produces about 4.1 million tons of scope 1 and 2 CO_2 emissions, with a standard deviation of 15.5 million tons. The carbon intensity of a firm, measured as the ratio of CO_2 emissions to the total value of assets, is about 141 tons per million of euros, with a standard deviation of 331 tons per million. Similarly, environmental scores of the firms in our sample show important variation. The mean environmental score is 0.61, with a standard deviation of 0.24.

For a deeper look at the distribution of CO_2 emissions and environmental scores, Table 2 reports summary statistics across different industry groups. Using the industry definitions from Kenneth French's website, we group our firms into four industry groups: consumer nondurable goods and consumer durable goods; manufacturing and mining; oil, utilities, and transportation; and services and other sectors. As shown in the table, industries in the service sector are the least carbon intensive, while those in the oil, utilities, and transportation sectors have on average the highest CO_2 intensity. Interestingly, the table also shows that firms in the least carbon-intensive industry group have the lowest mean environmental score, while the most carbon-intensive industry group has the highest environmental score. The correlation between CO_2 intensity and environmental scores within industry groups is negative in the services; and oil, utilities, and transportation industry groups. The table also shows that even within industry, there is important variation of carbon intensity as well as environmental scores.

The stock market reaction to the carbon tax news, as shown in Panel B of Table 1, is on average small but there is important cross-sectional variation in how firms reacted to the carbon tax news. Finally, the average firm in our sample has a market value of €13 billion, with a standard deviation of €21 billion. The average price-to-book value ratio is 2.2, with an average deviation of 1.9. About 23% of the firms in our sample participate in the EU Emissions Trading System.

Table 1: Summary Statistics of Firm Characteristics and Stock Returns Around the Carbon Tax News

	Mean	Std. Dev.	Percentile 5th	Percentile 95th
Panel A: Firm Characteristics				
CO_2 emissions (scope 1+2)	4,125	15,471	2	23,665
ln CO_2 emissions intensity	9.87	2.34	5.56	13.68
Environmental score	0.61	0.24	0.25	0.98
Market capitalization (billion €)	12.7	20.7	0.5	68.5
Price-to-book ratio	2.19	1.91	0.56	5.53
Return volatility	1.86	0.66	0.94	3.05
Profit margin	24.32	49.66	2.16	150.98
ETS participation	0.2	0.4	0	1
Panel B: Stock Returns				
CAPM-Adjusted (Dec. 16)	0.19	1.57	-2.09	3.39
CAPM-Adjusted (Dec. 16–18)	0.34	3.03	-2.97	4.82
CAPM-Adjusted Day (Dec. 16–20)	0.12	3.41	-5.88	4.73
Fama French-Adjusted (Dec. 16)	-0.22	1.62	-2.66	3.04
Fama French-Adjusted (Dec. 16–18)	0.12	3.10	-3.29	4.54
Fama French-Adjusted (Dec. 16–20)	-0.37	3.49	-6.67	4.14

This table presents summary statistics of environmental and financial characteristics for the 115 firms listed on the Prime Standard segment of the German stock exchange that are included in our sample. Carbon emissions, environmental scores, and financial characteristics, shown in Panel A, correspond to fiscal year 2018. Carbon intensity is computed as the ratio of carbon emissions to the firm's value of total assets, and normalized using the natural logarithm. Panel B presents summary statistics of risk-adjusted returns for three different event windows in 2019: the day after news about the carbon tax increase was announced (Dec. 16), the 3-day period that encompasses the news and the passage of the climate package in the lower house of Parliament (Dec. 16–18), and the 5-day period that encompasses the carbon tax news and the vote in the lower and upper houses of Parliament (Dec. 16–20). Returns are expressed in percentage points.

Table 2: Carbon Intensity and Environmental Score by Industry

	Carbon Intensity		*Env. Score*			
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Corr.**	**Count**
Services & Other	7.93	2.39	0.54	0.25	-0.23	37
Consumer	10.47	1.42	0.67	0.25	0.05	25
Manufacturing & mining	10.71	1.61	0.61	0.23	0.24	42
Oil, Utilities, & Transport	11.86	2.02	0.73	0.22	-0.36	11

This table presents summary statistics of the carbon intensity and the environmental score by industry for the 115 firms listed on the Prime Standard segment of the German stock exchange that are included in our sample. Carbon intensity is computed as the ratio of carbon emissions to the firm's value of total assets, and normalized using the natural logarithm. The data correspond to fiscal year 2018.

3 The Effect of the Carbon Tax News on Market Values of Sustainable Investment Strategies

3.1 Evidence from Portfolio Sorts

Portfolio sorts are an important and popular tool in empirical finance to evaluate asset pricing models and to identify potential profitable investment strategies. It is conventional practice, for example, to form portfolios ranked by some characteristic and test whether expected returns vary systematically with such characteristic.[18] We follow this popular practice and form portfolios according to a firm's exposure to climate change risks. We consider two proxy variables for a firm's exposure to climate change risks that are popular among environmentally minded investors: a firm's environmental score, and a firm's CO_2 footprint. If these two dynamic investing strategies are a good hedge against climate risks, investors would expect that in response to the announcement of a higher-than-expected carbon tax, portfolios with a low environmental score or a high carbon footprint would decline in value more than those with higher environmental scores or with a lower carbon footprint.

To test this hypothesis, Table 3 presents CAPM-adjusted returns (Panel A) and Fama French-adjusted returns (Panel B) on three portfolios around the carbon tax

[18]The CAPM, for example, implies a positive relationship between expected returns and market betas.

news. Firms are grouped into each portfolio based on their environmental score: the constituents of the *A-rated* portfolio have a score of A- or higher, the *B-rated* portfolio is comprised of firms with a score between B- and B+, and the stocks in the *C-rated & below* portfolio have scores below C+. Table 3 also reports the spread in returns between the portfolios with the highest and lowest environmental scores, which corresponds to a strategy that is long stocks of highly-rated firms and short firms at the bottom of the environmental score distribution. Finally, we report, in brackets, its associated 90 percent confidence interval. Each panel presents the portfolio returns for three different event windows: the day after news about the carbon tax increase was announced (Dec. 16), the 3-day period that encompasses the news and the passage of the climate package in the lower house of Parliament (Dec. 16–18), and the 5-day period that encompasses the carbon tax news and the vote in the lower and upper houses of Parliament (Dec. 16–20). The last rows of Table 3 report the following characteristics for each portfolio: number of stocks, the average (log) CO_2 emissions, CO_2 intensity (ratio of CO_2 emissions to total assets), the average environmental score, and the average (log) market value.

Our sort on environmental scores in Table 3 provides little evidence that holding a portfolio with stocks at the top of the environmental score distribution hedges the realization of climate policy risks. In particular, the portfolio with the A-rated stocks does not seem to have experienced higher returns relative to the portfolio holding stocks with low environmental scores around the December 16 event. In fact, the *C-rated & below* portfolio seems to outperform after the carbon tax news (Dec. 16) and this superior performance as measured by the return spread between high and low environmentally rated portfolios is statistically significant for both measures of risk-adjusted returns. The estimated return spread suggests that an investor long the *A-rated* portfolio and short the *C-rated & below* would have experienced a negative return around 0.6%. Over longer event windows, the return spread between the *A-rated* and *C-rated & below* portfolio is not statistically significant for both CAPM-adjusted returns or Fama French-adjusted returns.

Table 4 examines the stock market performance around the carbon tax news of

Table 3: Cumulative Risk-Adjusted Returns on Portfolios Sorted on a Firm's Environmental Score Around the Carbon Tax News

	Panel A: CAPM-adjusted			
	A-rated (1)	B-rated (2)	C-rated & below (3)	A-rated minus C-rated (1) – (3)
Dec. 16	-0.01	-0.15	0.54	-0.55 [-1.05, -0.07]
Dec. 16–18	0.69	-0.01	0.31	0.38 [-0.81, 1.17]
Dec. 16–20	0.57	-0.38	0.11	0.46 [-0.64, 1.63]
	Panel B: Fama French-adjusted			
	A-rated (1)	B-rated (2)	C-rated and below (3)	A-rated minus C-rated (1) – (3)
Dec 16	-0.45	-0.60	0.16	-0.61 [-1.16, -0.10]
Dec 16–18	0.31	-0.16	0.17	0.14 [-0.86, 1.18]
Dec 16–20	0.04	-0.91	-0.33	0.37 [-0.80, 1.53]
Portfolio Characteristics				
	A-rated	B-rated	C-rated and below	
No. of Stocks	35	30	50	
ln Market Value	25.72	23.57	22.70	
ln CO_2 emissions	16.17	14.77	13.28	
CO_2 intensity	11.17	11.93	11.31	
Environmental score	0.91	0.66	0.38	

This table presents CAPM and Fama French-adjusted equally-weighted returns on three portfolios around the carbon tax news sorted according to environmental scores. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019), as well as the three and five-day period beginning with the carbon tax news. The last column reports the return spread between the portfolios with the highest and lowest environmental scores and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

the following three portfolios sorted on CO_2 emissions intensity of a firm, which we define as the ratio of CO_2 emissions to the total value of assets: Low emitters (firms in the bottom 30%), Neutral (firms in the middle 40%), and High emitters (firms in the upper 30%). Our sort of stocks on CO_2 emissions intensity produces a strong negative relationship between the stock market response to the carbon tax news (Dec. 16) and the carbon footprint of the portfolio. For one thing, the portfolio of low emitters increases in value the day when the unexpected increase in the carbon tax is announced, while the portfolio of high emitters declines in value. The estimated return spread suggests that a strategy long low carbon intensity firms and short high carbon intensity firms leads to a positive return of around 1.3% the day of the carbon day news, which is highly statistically significant and represents around four-fifths of a standard deviation of risk-adjusted returns over this event window. Moreover, as shown in Figure 1, the return spread between low and high carbon intensive portfolios remains positive and increases modestly as we expand the event window. The results are generally supportive of the effectiveness of investment strategies that use a firm's carbon intensity to screen firms in search for investment opportunities that hedge risks from policies to combat climate change.

As shown in the Appendix, our conclusions are robust to reasonable variations to the way we construct the climate change risk-hedging portfolios. First, we compute value-weighted risk-adjusted returns to alleviate the concern that our results are driven by small firms with volatile returns. Second, we use environmental scores from other prominent data providers as an alternative proxy for a firm's climate risk exposure. Third, we form portfolios using alternative proxy variables for a firm's carbon footprint; namely, CO_2 emissions, and the ratio of CO_2 emissions to the total market value.

3.2 Evidence from Cross-Sectional Regressions

We now assess our claim that companies with a higher environmental score or a smaller carbon footprint should outperform in response to the carbon tax news using

Table 4: Cumulative Risk-Adjusted Return on Portfolios Sorted on CO_2 Emissions Intensity Around the Carbon Tax News

	Panel A: CAPM-adjusted			
	Low emitters	Neutral	High emitters	Low minus High
Dec 16	0.88	0.09	-0.34	1.22
				[0.36, 1.73]
Dec 16–18	1.59	-0.76	0.58	1.01
				[-0.12, 2.21]
Dec 16–20	1.57	-0.76	-0.12	1.70
				[0.34, 3.02]
	Panel B: Fama French-adjusted			
	Low emitters	Neutral	High emitters	Low minus High
Dec 16	0.54	-0.39	-0.73	1.27
				[0.40, 1.75]
Dec 16–18	1.43	-0.91	0.22	1.21
				[-0.03, 2.15]
Dec 16–20	1.16	-1.28	-0.66	1.82
				[0.41, 3.22]
Portfolio Characteristics				
	Low	Mid	High	
No. of Stocks	34	46	35	
ln Market Value	23.20	23.42	23.09	
ln CO_2 emissions	11.51	13.22	16.36	
CO_2 intensity	6.79	9.74	13.31	
Environmental score	0.58	0.59	0.67	

This table presents CAPM and Fama French-adjusted equally-weighted returns on three portfolios around the carbon tax news sorted according to carbon emissions intensity. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019), as well as the three and five-day period beginning with the carbon tax news. The last column reports the return spread between the portfolios with the highest and lowest emissions intensity and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

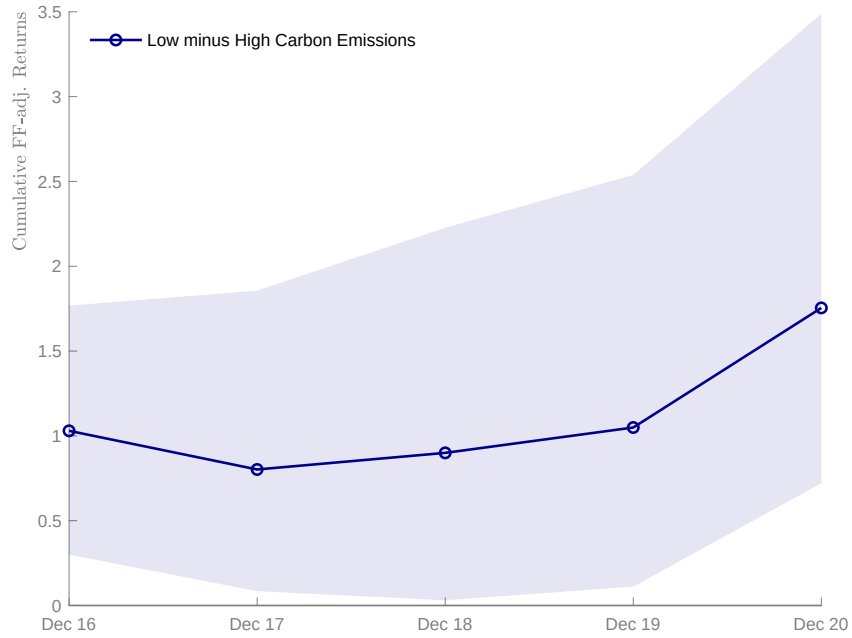

Figure 1: **Fama French-adjusted Cumulative Returns Around the Carbon Tax News and CO_2 Emissions Intensity**

This figure shows the spread between cumulative returns on portfolios with lowest and highest carbon emissions intensity around the carbon tax news. Returns are Fama French-adjusted and are shown for each day in the event window beginning December 16 and ending December 20.

a cross-sectional regression model (see equation (1)).

We begin by estimating the variation in the response of firms' stock returns to the carbon tax news with firms' environmental scores. To ease the interpretation of the coefficient estimate on the environmental score (ENVSCORE), we standardize this variable such that the cross-sectional standard deviation of the environmental score is equal to 1. We estimate the cross-sectional regression using the risk-adjusted returns around the carbon tax news and we control for the following firm's financial characteristics: (log) market capitalization ($\ln$ MKTCAP); (log) price-to-book value ratio ($\ln$ PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We also include industry fixed-effects for the following industry groups: consumer nondurable and durable goods; manufacturing, and mining; oil, utilities, and transportation; and services. We also include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns.

Shown in Table 5, the estimation results provide no evidence that firms with a high environmental score performed any better than those with a low environmental score around the carbon tax news. The model performs poorly in two ways. First, environmental scores do not explain the immediate response of stock prices to the unexpected increase in the carbon tax. Column 1 of Panels A and B displays the estimates of the cross-sectional regression for the day news of the last-minute agreement to increase the carbon tax broke (Dec. 16). Estimates of the coefficient on the environmental score show that one cannot reject the hypothesis that differences in the initial reaction of stock prices to the carbon tax news are unrelated to a firm's environmental score for both CAPM- and Fama French-adjusted returns. Second, estimates of the response of stock prices over the 5-day period that encompasses the carbon tax news and the vote in the lower and upper houses of Parliament—the results in columns 2 and 3—provide mixed evidence of a positive relationship between the stock price reaction and the environmental score. While the CAPM- and Fama-adjusted returns are positively related to a firm's environmental score, a one-tailed hypothesis test suggests that in most

cases we cannot reject the null hypothesis that the coefficient on the environmental score is negative or zero under conventional confidence levels.

The lack of strong evidence of a positive relationship between the reaction to the carbon tax news and the environmental score might reflect the fact that environmental scores are measured with noise. Berg et al. (2021) argues that regression estimates of stock returns on ESG scores are biased toward zero and the bias increases with the noise in the estimated ESG measure, which is also likely true for the environmental component of ESG scores.[19] Thus, to reduce the amount of measurement error in the environmental scores, we restrict our sample to the constituents of the DAX index, which are the largest firms traded in the Frankfurt Stock Exchange; it stands to reason that the environmental performance of these firms is likely measured with higher precision because these firms provide high quality inputs that rating agencies use to compute the scores.[20] In addition, we also estimate the cross-sectional regressions using the environmental scores from four different rating agencies: Refinitiv, Carbon Disclosure Project, RobecoSAM, and S&P Global, which provide alternative and complementary information about a firm's climate risk.

Table 6 presents the estimates from this exercise. Column 1 presents the estimated coefficients using the immediate stock market reaction to the carbon tax news (Dec. 16), and column 2 reports the cross-sectional regression estimates using the 5-day cumulative return (Dec. 16–20). Panel A and Panel B present the results using CAPM- and Fama French-adjusted returns, respectively.[21] We continue to find little support of a positive relationship between the immediate stock market reaction and the environmental score across all the rating agencies in our sample. Most notably, the coefficient on the environmental score, shown in column 2, is economically and statistically smaller than the baseline estimates using the full sample. The insensitivity of our baseline results using the full sample to restricting the sample to the

[19] Berg et al. (2021) proposes relying on complementary ratings. In particular, Berg et al. (2021) develops an instrumental variable approach to overcome the problem of measurement error. The instrument is constructed from environmental scores from several data providers.

[20] The German firms listed in the DAX, for example, produce corporate social responsibility reports, which are a key input to ESG rating agencies.

[21] These regressions do not include industry fixed effects because of the small sample size in each industry category.

Table 5: Stock Returns Response to the Carbon Tax News and Environmental Scores

	Panel A: CAPM-adjusted Return			*Panel B: Fama French-adjusted Return*		
	(1)	(2)	(3)	(1)	(2)	(3)
	Dec. 16	**Dec. 16–18**	**Dec. 16–20**	**Dec. 16**	**Dec. 16–18**	**Dec. 16–20**
ENVSCORE	0.017	0.879*	1.149**	-0.068	0.701	0.826*
	(0.174)	(0.509)	(0.463)	(0.174)	(0.469)	(0.463)
ln PRICEBOOK	0.580**	0.814	0.903*	0.426*	0.954**	1.245***
	(0.234)	(0.525)	(0.542)	(0.215)	(0.415)	(0.439)
ln MKTCAP	-0.302*	-0.868**	-0.951***	-0.218*	-0.657**	-0.560**
	(0.159)	(0.350)	(0.313)	(0.118)	(0.269)	(0.264)
RETVOL	-0.338	-0.011	-0.292	-0.496*	-0.472	-1.204**
	(0.254)	(0.340)	(0.433)	(0.282)	(0.346)	(0.494)
PROFIT	0.005*	0.007	0.012**	0.006*	0.007*	0.012**
	(0.003)	(0.005)	(0.005)	(0.003)	(0.004)	(0.005)
ETS	0.569**	0.768	0.984	0.591**	0.901	1.168*
	(0.267)	(0.527)	(0.619)	(0.288)	(0.571)	(0.679)
R^2	0.19	0.10	0.27	0.18	0.10	0.22
Obs.	115	115	115	115	115	115

This table presents the estimated coefficients from the following cross-sectional regression:

$$AR^i_\tau = \phi_0 + \phi_1 \mathrm{E}^i_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}^i_{t-1} + \varepsilon^i_t$$

where the dependent variable is firm i's stock market return around the carbon tax news, CAPM-adjusted (Panel A) and Fama French-adjusted (Panel B). The key explanatory variable is a firm's environmental score (ENVSCORE), which we standardize to have a cross-sectional standard deviation equal to 1. The vector $\boldsymbol{x}^i_{t-1}$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns. All regressions include industry fixed-effects constructed using the Fama-French industry classification. The sample includes German publicly traded firms that are part of the Prime Standard segment and that either report their carbon emissions or have emissions estimated from energy use. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

largest German firms and to using scores from different data providers strengthens our confidence in our conclusion that environmental scores do not explain the observed reaction in asset valuations to the carbon tax news. Moreover, measurement error in environmental scores does not seem to be the key explanation for the lack of correlation between environmental scores and the stock market performance of firms around the carbon tax news since environmental scores of the largest companies are likely measured with better precision relative to the rest of the sample.

We now turn to examining the ability of a firm's CO_2 intensity to predict the stock return reaction to the carbon tax news. The estimates in column 1 of Table 7 show that, contrary to the results for the environmental score, a firm's carbon emissions intensity explains the initial stock price reaction to the carbon tax news for both CAPM- and Fama French-adjusted returns. The estimated coefficient on CO_2 intensity suggests that a one standard deviation decline in CO_2 intensity is associated with an increase in market value of 0.3 percentage points, which is equivalent to a one-fifth of the standard deviation of risk-adjusted returns over this window. As the horizon over which the regression is estimated increases, shown in columns 2 and 3, the economic importance of carbon emissions intensity rises, with the estimated coefficient suggesting an increase in risk-adjusted returns of 0.8 percentage points over a five-day window—around a one-third of a standard deviation of the variation of risk-adjusted returns over this event window—from a decline in a one standard deviation of a firm's carbon emissions intensity. The increase in the coefficient on CO_2 intensity as we expanded the event window to capture the votes in the lower and upper houses of the German Parliament suggests that the political agreement to increase the carbon tax (on Dec. 18 and Dec. 20) probably also conveyed new information about the likelihood of and risk from further policies aimed at reducing carbon emissions in Germany.

In Table 8, we assess the sensitivity of our results to two variations in the sample by estimating the cross-sectional regression. First, restricting our sample to the largest publicly traded firms in Germany, and, second, by excluding firms "targeted" by the carbon tax (firms in the oil, utilities, and transportation sector). Shown in column 1 of panels A and B, the coefficient estimate on CO_2 emissions intensity for a sample of the

Table 6: Stock Returns Response of the Largest German Firms to the Carbon Tax News

Panel A: CAPM-adjusted Return								
	Refinitiv		*CDP*		*RobecoSAM*		*S&P Global*	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
	Dec. 16	**Dec. 16–20**	**Dec. 16**	**Dec. 16–20**	**Dec. 16**	**Dec. 16–20**	**Dec. 16**	**Dec. 16–20**
ENVSCORE	-0.322	0.274	-0.704**	-2.545**	-0.013	-0.205	-0.080	-0.276
	(0.340)	(0.689)	(0.255)	(0.801)	(0.269)	(0.801)	(0.371)	(1.152)
ln PRICEBOOK	-0.299	-0.583	0.606	0.370	0.040	-1.043	-0.073	-1.047
	(0.695)	(1.562)	(0.422)	(1.004)	(0.495)	(1.310)	(0.546)	(1.353)
ln MKTCAP	0.040	-0.507	-0.067	-0.274	-0.060	-0.271	-0.111	-0.236
	(0.242)	(0.713)	(0.267)	(0.941)	(0.319)	(0.992)	(0.447)	(1.530)
RETVOL	-0.385	-0.641	-1.250***	-1.988*	-0.219	-1.007	-0.921	-1.360
	(0.284)	(0.707)	(0.399)	(1.215)	(0.399)	(0.994)	(0.539)	(1.459)
PROFIT	0.002	0.012	0.009	0.069	0.006	-0.001	0.003	-0.005
	(0.009)	(0.021)	(0.010)	(0.025)	(0.013)	(0.034)	(0.015)	(0.048)
ETS	0.358	0.643	0.609	1.462	0.384	0.449	0.233	0.394
	(0.233)	(0.607)	(0.394)	(1.090)	(0.384)	(0.847)	(0.314)	(0.812)
R^2	0.22	0.23	0.43	0.47	0.18	0.23	0.19	0.23
Obs.	28	28	25	25	27	27	26	26

Table 6: Stock Returns Response of the Largest German Firms to Carbon Tax News (cont.)

Panel B: Fama French-adjusted Return

	Refinitiv		*CDP*		*RobecoSAM*		*S&P Global*	
	(1) **Dec. 16**	(2) **Dec. 16–20**	(1) **Dec. 16**	(2) **Dec. 16–20**	(1) **Dec. 16**	(2) **Dec. 16–20**	(1) **Dec. 16**	(2) **Dec. 16–20**
ENVSCORE	-0.663	0.841	-0.710**	-1.896**	0.071	-0.079	0.026	-0.227
	(0.487)	(1.007)	(0.260)	(0.826)	(0.292)	(0.756)	(0.345)	(0.921)
ln PRICEBOOK	-0.069	1.177	0.069	0.884	0.251	0.787	-0.0972	0.377
	(0.505)	(1.224)	(0.317)	(0.770)	(0.392)	(1.024)	(0.467)	(1.211)
ln MKTCAP	-0.104	-0.890	0.114	-0.062	-0.152	-0.757	-0.223	-0.651
	(0.244)	(0.672)	(0.293)	(0.902)	(0.328)	(0.857)	(0.401)	(1.149)
RETVOL	-0.301	-1.034***	-1.359**	-3.558	0.000	-1.393	-0.876	-1.622
	(0.383)	(0.884)	(0.478)	(1.328)	(0.439)	(0.958)	(0.587)	(1.437)
PROFIT	0.010	0.042*	0.007	0.002	0.022**	0.032	0.017	0.727
	(0.014)	(0.024)	(0.008)	(0.028)	(0.011)	(0.034)	(0.010)	(0.033)
ETS	0.408	1.040	0.598	1.256	0.625	0.910	0.382	0.951
	(0.319)	(0.682)	(0.401)	(1.065)	(0.379)	(0.824)	(0.324)	(0.712)
R^2	0.13	0.18	0.40	0.43	0.11	0.16	0.17	0.18
Obs.	28	28	25	25	27	27	26	26

This table presents the estimated coefficients from the following cross-sectional regression:

$$AR^i_\tau = \phi_0 + \phi_1 \mathrm{E}^i_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}^i_{t-1} + \varepsilon^i_t$$

where the dependent variable is firm i's stock market return around the carbon tax news, CAPM-adjusted (Panel A) and Fama French-adjusted (Panel B). The key explanatory variable is a firm's environmental score (ENVSCORE), which we standardize to have a cross-sectional standard deviation equal to 1. The vector $\boldsymbol{x}^i_{t-1}$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns. The sample includes firms that are constituents of the DAX index. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

largest firms in Germany is quite similar to the estimate using our baseline sample, which suggests that the reported and estimated carbon emissions in our sample are not prone to measurement error. This is not very surprising given that firms and rating agencies follow the guidelines in the Greenhouse Gas Protocol to report emissions. The coefficient estimate on CO_2 intensity excluding the firms in the oil, utilities, and transportation sector, shown in column 2, is also very close to the estimates from the baseline model, lending support to the hypothesis that the carbon tax news likely led to a reassessment of the government's commitment to strong implementation of future policies to curb carbon emissions.

The empirical evidence presented so far demonstrates that a firm's carbon emissions intensity is a robust predictor of a firm's stock market reaction to the carbon tax news, while environmental scores are not. One explanation for the lack of predictive power of environmental scores may be a potential adjustment in asset prices in anticipation of an increase in the carbon tax the week politicians announced that they were going to negotiate some aspects of the climate package. To assess this, we run the cross-sectional regression for the days following the announcement of the mediation process (Dec. 9 and Dec. 9–11). As shown in Table 9, the response of stock prices is unrelated to CO_2 emissions intensity, which suggests that the carbon tax increase was likely unexpected. Importantly, environmental scores are not related to the stock return reaction over that period, confirming that our initial finding is unlikely due to markets having already priced in the increase in the carbon tax the days before the announcement.

4 Carbon Tax News and Earnings Forecasts

Having shown that carbon intensity does a better job in explaining the cross-sectional reaction in equity values to the carbon tax news than environmental scores, we now ask what lies behind the success of an investment strategy that uses a firm's carbon footprint to hedge the unexpected increase in the carbon tax. This section demonstrates that carbon intensity explains much of the cross-sectional reaction to the car-

Table 7: Stock Returns Response to Carbon Tax News and Carbon Intensity

	Panel A: CAPM-adjusted Return			*Panel B: Fama French-adjusted Return*		
	(1)	(2)	(3)	(1)	(2)	(3)
	Dec. 16	**Dec. 16–18**	**Dec. 16–20**	**Dec. 16**	**Dec. 16–18**	**Dec. 16–20**
CO_2 INTENSITY	-0.145**	-0.274*	-0.305*	-0.133*	-0.278**	-0.307**
	(0.065)	(0.116)	(0.155)	(0.069)	(0.114)	(0.149)
ln PRICEBOOK	0.641***	0.694	0.721	0.478**	0.906**	2.864***
	(0.228)	(0.449)	(0.528)	(0.213)	(0.378)	(0.413)
ln MKTCAP	-0.331***	-0.449***	-0.390*	-0.273***	-0.394***	-0.286*
	(-0.120)	(0.164)	(0.211)	(0.092)	(0.148)	(0.172)
RETVOL	-0.312	0.116	-0.135	-0.485*	-0.290	-0.993*
	(0.259)	(0.361)	(0.465)	(0.284)	(0.370)	(0.515)
PROFIT	0.006*	0.007*	0.012**	0.006*	0.008**	0.013***
	(0.003)	(0.004)	(0.005)	(0.003)	(0.004)	(0.005)
ETS	0.805***	1.584***	1.966***	0.782**	1.613***	1.973***
	(0.288)	(0.577)	(0.644)	(0.307)	(0.611)	(0.720)
R^2	0.22	0.09	0.25	0.20	0.10	0.22
Obs.	115	115	115	115	115	115

This table presents the estimated coefficients from the following cross-sectional regression:

$$AR^i_\tau = \phi_0 + \phi_1 \mathrm{E}^i_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}^i_{t-1} + \varepsilon^i_t$$

where the dependent variable is firm i's stock market return around the carbon tax news, CAPM-adjusted (Panel A) and Fama French-adjusted (Panel B). The key explanatory variable is a firm's carbon emissions intensity (CO_2 INTENSITY) measured as the log of the ratio of CO_2 emissions to total assets. The vector $\boldsymbol{x}^i_{t-1}$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns. All regressions include industry fixed-effects constructed using the Fama-French industry classification. The sample includes German publicly traded firms that are part of the Prime Standard segment and that either report their carbon emissions or have emissions estimated from energy use. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 8: Sensitivity of the Relationship Between Stock Returns Response to Carbon Tax News and CO_2 Intensity

	Panel A: CAPM-adjusted Return		*Panel B: Fama French-adjusted Return*	
	(1)	(2)	(1)	(2)
	DAX firms	Ex. Fossil Fuels	DAX firms	Ex. Fossil Fuels
CO_2 INTENSITY	-0.207**	-0.163**	-0.227***	-0.150**
	(0.079)	(0.071)	(0.069)	(0.074)
ln PRICEBOOK	0.433	0.691**	0.387	0.506**
	(0.363)	(0.277)	(0.244)	(0.239)
ln MKTCAP	-0.349	-0.359***	-0.396*	-0.301***
	(0.243)	(0.126)	(0.230)	(0.097)
RETVOL	-0.098	-0.415	-0.073	-0.582*
	(0.235)	(0.288)	(0.264)	(0.304)
PROFIT	0.000	0.006*	0.003	0.006*
	(0.011)	(0.003)	(0.012)	(0.003)
ETS	0.757**	0.813**	0.787**	0.805**
	(0.329)	(0.311)	(0.360)	(0.341)
R^2	0.41	0.22	0.36	0.21
Observations	28	104	28	104

This table presents the estimated coefficients from the following cross-sectional regression:

$$AR^i_\tau = \phi_0 + \phi_1 \mathrm{E}^i_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}^i_{t-1} + \varepsilon^i_t$$

where the dependent variable is firm i's stock market return around the carbon tax news, CAPM-adjusted (Panel A) and Fama French-adjusted (Panel B). The key explanatory variable is a firm's carbon emissions intensity (CO_2 INTENSITY) measured as the log of the ratio of CO_2 emissions to total assets. The vector $\boldsymbol{x}^i_{t-1}$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns. The sample in column 1 includes German publicly traded firms that are part of the DAX; the sample in column 2 excludes firms in the oil, utilities, and transportation sector. Regressions in column 2 include industry fixed-effects constructed using the Fama-French industry classification. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 9: Sensitivity to Potential Stock Market Reaction Before Announcement of Carbon Tax News

	Panel A: CAPM-adjusted Return				*Panel B: Fama French-adjusted Return*			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Dec. 9	**Dec. 9–12**	**Dec. 9**	**Dec. 9–12**	**Dec. 9**	**Dec. 9–12**	**Dec. 9**	**Dec. 9–12**
CO_2 INTENSITY	0.093	0.128			0.086	0.108		
	(0.065)	(0.098)			(0.063)	(0.099)		
ENVSCORE			-0.171	-0.404			-0.206	-0.287
			(0.176)	(0.298)			(0.193)	(0.335)
ln PRICEBOOK	-0.607***	-1.089***	-0.611***	-1.143***	-0.260	-0.753*	-0.272*	-0.773
	(0.274)	(0.442)	(0.286)	(0.434)	(0.248)	(0.445)	(0.244)	(0.422)
ln MKTCAP	0.006	-0.103	0.073	0.080	0.032	-0.278*	0.109	-0.169
	(0.133)	(0.206)	(0.165)	(0.267)	(0.097)	(0.165)	(0.131)	(0.241)
RETVOL	0.257	-0.537	0.296	-0.459	0.022	-0.886*	0.076	-0.812*
	(0.256)	(0.447)	(0.266)	(0.443)	(0.281)	(0.504)	(0.278)	(0.476)
PROFIT	-0.001	-0.002	-0.000	-0.002	-0.000	-0.000	-0.000	0.000
	(0.001)	(0.003)	(0.001)	(0.003)	(0.001)	(0.003)	(0.001)	(0.003)
ETS	-0.161	-0.310	0.058	0.065	-0.130	-0.401	0.087	-0.118
	(0.312)	(0.636)	(0.274)	(0.651)	(0.363)	(0.655)	(0.321)	(0.671)
R^2	0.094	0.111	0.094	0.111	0.027	0.115	0.027	0.115
Observations	115	115	115	115	115	115	115	115

This table presents the estimated coefficients from the following cross-sectional regression:

$$AR^i_\tau = \phi_0 + \phi_1 \mathrm{E}^i_{t-1} + \boldsymbol{\phi}' \boldsymbol{x}^i_{t-1} + \varepsilon^i_t$$

where the dependent variable is firm i's stock market return around the carbon tax news, CAPM-adjusted (Panel A) and Fama French-adjusted (Panel B). The key explanatory variable is a firm's carbon emissions intensity (CO_2 INTENSITY) measured as the log of the ratio of CO_2 emissions to total assets. The vector $\boldsymbol{x}^i_{t-1}$ includes controls for the following firm's financial characteristics reported before the event: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). We include the firm's exposure to the SMB and HML factors as captured by their estimated betas (BSMB, BHML) when we use as dependent variable the CAPM-adjusted returns. All regressions include industry fixed-effects constructed using the Fama-French industry classification. The sample includes German publicly traded firms that are part of the Prime Standard segment and that either report their carbon emissions or have emissions estimated from energy use. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

bon tax news because carbon intensity predicts revisions in expected profitability after the unexpected carbon tax news while environmental scores do not.

We collect data on analysts' forecasts from the Institutional Brokers' Estimate System (I/B/E/S) provided by Refinitiv.[22] Our empirical analysis uses forecasts of earnings per share over the next two years, and forecasts of long-term growth in earnings that represent annual growth over the next three to five years. We use monthly consensus forecasts reported a month before the carbon tax news (November 13, 2019) and a month after the event (January 16, 2020). Using information of forecasts for earnings per share over the next years, we compute the revision in earnings forecasts over the next two years as the change in earnings forecasts between a month before the carbon tax news and a month after the tax news. The two-year forecast window covers the year before and after the implementation of the carbon tax signed into law on December 2019. Similarly, we define revisions in earnings long-term growth forecasts as the change in forecasts over the same period.

Table 10 shows summary statistics for three measures of earnings forecast revisions: the revision of forecasts of earnings as percentage of the initial earnings forecast, the revision of forecasts of earnings per share expressed in cents of €, and the revision of forecasts of annual growth in earnings over the next three to four years. On average, forecasts of earnings over the next two years were marked down about 2% relative to the initial forecast (or 8 cents) between a month before and after the carbon tax news, with a standard deviation of 14%, suggesting that there is important variation in forecasts revisions. Forecasts of earnings over the next year were marked down about 2.5% on average relative to the initial forecast (or about 9.5 cents), with a standard deviation of about 20%. Median earnings forecast revisions tend to be smaller in magnitude than mean earnings forecast revisions: the median forecast over the next two years was marked down 0.68%, and the median forecast over the next year was marked down about half a percent. The difference between median and average fore-

[22]The I/B/E/S is a unique service that gathers and compiles estimates made by stock analysts on the future earnings for publicly traded companies of interest to portfolio managers and institutional investors. Refinitiv collects data for 22,000 active companies in 100 countries, and sourced from over 18,000 analysts.

Table 10: Summary Statistics of Analyst Earnings Forecast Revisions

	Mean	Median	Std. Dev.
1 year (cents of €)	-9.45	-2.00	24.80
1 year (pct. change)	-2.48	-0.55	19.79
2 years (cents of €)	-8.30	-1.50	22.87
2 years (pct. change)	-2.20	-0.68	13.65
Long-term growth	-0.24	0.00	2.98

This table presents summary statistics of analyst earnings forecast revisions from firms listed on the Prime Standard segment of the German stock exchange with stock prices above €5 that report their carbon emissions. Earnings forecast revisions are defined as the difference between the monthly consensus forecast on November 13, 2019 and January 16, 2020. Earnings forecasts are from the I/B/E/S system provided by Refinitiv.

casts revisions is driven by a few large downward revisions, which we drop from the sample in our econometric analysis below. On average, forecasts of long-term growth were marked down between a month before and after the carbon tax news. The median forecast revision to long term growth, however, was zero. There is important variation in revisions to forecasts of annual long-term growth in earnings, as this is important for obtaining precise estimates of the effect of carbon intensity on earnings revisions.

To begin, we examine the ability of a firm's carbon intensity to predict analysts' revisions of earnings forecasts around the unexpected carbon tax increase by estimating the following econometric model,

$$\frac{\mathbb{F}_{\tau+\delta}\left[e_i\right] - \mathbb{F}_{\tau-\delta}\left[e_i\right]}{\mathbb{F}_{\tau-\delta}\left[e_i\right]} = \phi_0 + \phi_1 \, \text{CO}_2 \text{ INTENSITY}_{i,t} + \boldsymbol{\phi}' \, \mathbf{x}_{i,t} + \varepsilon_{i,t} \tag{3}$$

where $\mathbb{F}_{\tau+\delta}\left[e_i\right] - \mathbb{F}_{\tau-\delta}\left[e_i\right]$ is the change in forecasts of earnings made a month before the tax news, $\tau-\delta$, and a month after the tax news, $\tau+\delta$, $\mathbb{F}_{\tau-\delta}\left[e_i\right]$ is the forecast before the carbon tax news. The key explanatory variable is a firm's (log) carbon emissions intensity as captured by the ratio of CO_2 emissions to the total value of assets (CO_2 INTENSITY). To control for other factors that may affect the analysts's forecasts revisions, the vector $\mathbf{x}_{i,t}$ includes controls for size as captures by a firm's market cap-

italization ($\ln$ MKTCAP), price-to-book value per share ($\ln$ PRICEBOOK), profit margin (PROFIT), the volatility of stock returns over the past 12 months (RETVOL), the return on equity over the past 12 months (MOMENTUM). To control for industry variation, we include a dummy variable for firm's that participate in the EU ETS (ETS), and industry dummy variables. As in the stock return cross-sectional regressions, the financial characteristics of a firm are from fiscal year $t = 2018$, which are known to analysts when they made their forecasts.

Table 11 presents the results from our linear regression model (3). Column 1 presents the estimates of a regression of revisions in earnings over the next two years onto CO_2 intensity. The estimated coefficient on carbon intensity suggests that a one standard deviation increase in carbon intensity leads to a statistically significant downward revision of earnings forecasts of 2.2 percentage points around the unexpected increase in the carbon tax, or close to one-fifth of a standard deviation of earnings revisions over that horizon. Column 2 reports estimates of the relationship between revisions of forecasts of long-term growth in earnings and CO_2 intensity. The regression estimate suggests that analysts marked down their forecast for long-term growth in earnings by 0.63 percentage points around the carbon tax news, a one-sixth standard deviation of growth in earnings forecast revisions over this period. Our estimates highlight that the carbon tax announcement changed not only analysts' expectations of firms' level of earnings but also their growth trajectory over the next three to five years.

Since the carbon tax was signed into law at the end of 2019 and was scheduled to take effect in 2021, earnings forecasts across two years would capture both the year between announcement and implementation as well as the first year the carbon tax was in effect. Revisions to one year earnings forecasts, however, provide insight about changes in analysts' outlook on earnings the year between the announcement of the carbon tax and its implementation. Accordingly, column 3 of Table 11 present results using one-year earnings forecast revisions. The estimated coefficient on carbon intensity defined suggests that a one standard deviation increase in carbon intensity leads to a downward revision in the earnings forecast of 3.7 percentage points, or about a fifth of a standard deviation. Interestingly, earnings of carbon intensive firms

are expected to decline relative to their less carbon intensive counterparts before the carbon tax goes into effect, suggesting that the response in asset prices reflects factors beyond the cost of the carbon tax.

Next, we explore whether environmental scores can also predict earnings forecast revisions around the carbon tax news. As shown in columns 1 and 2 of Table 12, we find that the relationship between a firm's environmental score and forecasts revisions of both the level of earnings and the growth of earnings over the next several years is statistically insignificant. Therefore, our findings that carbon intensity predicts the revisions in earnings forecast around the announcement of the carbon tax news and that environmental scores are unrelated to analysts' earnings revisions are consistent with the findings presented in the previous section and make it unlikely that the main conclusions are due to chance.

Table 11: Earnings Forecast Response to Carbon Tax News and CO_2 Intensity

	2-year earnings	Long-term growth	1-year earnings
CO_2 INTENSITY	-0.930**	-0.279*	-1.652**
	(0.406)	(0.149)	(0.707)
lnPRICEBOOK	-0.364	0.032	1.539
	(1.816)	(0.188)	(2.894)
lnMKTCAP	-1.260**	0.217	-2.660*
	(0.538)	(0.175)	(1.335)
MOMENTUM	0.083***	-0.005	0.158***
	(0.022)	(0.014)	(0.050)
RETVOL	-6.911***	0.281	-2.831
	(2.325)	(0.433)	(3.194)
PROFIT	-0.025	0.004*	0.011
	(0.0166)	(0.002)	(0.023)
ETS	-0.917	-1.855*	9.173*
	(3.677)	(1.106)	(5.341)
R^2	0.34	0.24	0.20
Observations	110	76	104

This table presents the estimated coefficients from cross-sectional regressions. The dependent variables are forecast revision as a percent change in earnings over the next two years, long-term growth in earnings, and earnings over the next year. The key explanatory variable is a firm's CO_2 intensity measured as the log of the CO_2 2 emissions to total assets ratio. The control variables are: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); stock return over the past 12 months (MOMENTUM); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). All regressions include industry fixed-effects constructed using the Fama-French industry classification. The sample includes German publicly traded firms that are part of the Prime Standard segment and that either report their carbon emissions have emissions are estimated from energy use. Observations with a Cook distance greater than 3 are dropped. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 12: Earnings Forecast Response to Carbon Tax News and Environmental Score

	2-year earnings	Long-term growth	1-year earnings
ENVSCORE	0.045	0.237	0.156
	(0.988)	(0.170)	(2.029)
lnPRICEBOOK	1.708**	0.102	0.080
	(0.790)	(0.178)	(3.386)
lnMKTCAP	-0.582	-0.231*	-2.712
	(0.516)	(0.134)	(1.763)
MOMENTUM	0.073***	-0.011*	0.163***
	(0.018)	(0.006)	(0.046)
RETVOL	-3.493**	-0.584*	-7.581**
	(1.432)	(0.308)	(3.131)
PROFIT	-0.003	0.002	0.001
	(0.009)	(0.002)	(0.024)
ETS	2.257	-0.209	2.348
	(1.670)	(0.458)	(6.485)
R^2	0.28	0.20	0.23
Observations	109	80	108

This table presents the estimated coefficients from cross-sectional regressions. The dependent variables are forecast revision as a percent change in earnings over the next two years, long-term growth in earnings, and earnings over the next year. The key explanatory variables are a firm's environmental score. The control variables are: (log) market capitalization (ln MKTCAP); (log) price-to-book value ratio (ln PRICEBOOK); profit margin (PROFIT); stock return over the past 12 months (MOMENTUM); the volatility of stock returns over the past 12 months (RETVOL); and an indicator if a firm participates in the EU Emissions Trading System (ETS). All regressions include industry fixed-effects constructed using the Fama-French industry classification. The sample includes German publicly traded firms that are part of the Prime Standard segment and that either report their carbon emissions have emissions are estimated from energy use. Observations with a Cook distance greater than 3 are dropped. Standard errors robust to heteroskedasticity are shown in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

5 Concluding Remarks

In this paper, we assess the ability to hedge transition risks from climate change of two investment strategies that integrate ESG scores or carbon emissions data directly into the security selection process. We conduct our analysis around the approval of the German carbon tax for the transport and buildings sectors in December of 2019 to exploit the plausibly unexpected increase in the carbon tax. We show that while the stock price of firms with a high environmental score did not perform any better than the stock price of a firm with a low environmental score, the carbon intensity of a firm

is a robust predictor of the reaction of stock prices to the unexpected increase in the carbon tax. We demonstrate that carbon intensity does a better job in explaining the cross-sectional reaction in equity values to the carbon tax news than environmental scores because carbon intensity predicts revisions in expected profitability after the unexpected carbon tax news while environmental scores do not. Importantly, investors marked down not only the level of earnings but also their forecasts for the growth in earnings over the next several years for carbon intensive firms relative to their less carbon intensive counterparts. All in all, our empirical evidence suggests that investors should look through environmental ratings and consider a firm's carbon footprint to hedge climate change risks.

Our results speak to the ongoing debates on metrics to assess a firm's exposure to climate change risks. Investors and regulatory agencies are increasingly concerned about the risks climate change could pose to businesses' operations and financial health. Recent debates over disclosure of information about a firm's resilience or exposure to climate risks—including those from policies to combat climate change, namely, transition risks—are contentious.[23] The ability of a firm's carbon emissions to predict the change in a firm's market value in response to a higher carbon tax highlights the benefits of having high-quality and reliable measures of firm-level carbon emissions. Our results indicate that disclosing Scope 1 and Scope 2 carbon emissions would help investors and regulators have a simple and comparable metric that captures a firm's exposure to climate policy risk. In practice, this metric provides investors, financial advisers and asset managers information about the exposure of their portfolios and financial products to climate policy risks.[24]

While there is strong evidence that a firm's carbon emissions intensity is a robust predictor of a firm's stock market reaction to the carbon tax news in Germany, the generalization of our findings to other climate transition risks, both physical and

[23]The SEC https://www.reuters.com/legal/legalindustry/will-secs-proposed-climate-risk-disclosure-rules-survive-supreme-court-scrutiny-2022-08-05/.

[24]For example, new regulations from the Securities and Exchange Commission may change the landscape of using firm carbon footprints to select stocks. Beginning in fiscal year 2023 or 2024, firms will be required to report their carbon emissions and climate-related risks. For more details, see Washington Post, March 21, 2022, "The SEC Proposed a Landmark Climate Disclosure Rule. Here's What to Know."

transition risks, is unclear. In particular, the equity market reaction might be different to future policies aiming at speeding the transition to a zero emissions economy because investors, for example, might have more information about the potential effects of climate change on the economy or become more attuned to risks from climate change. Understanding the predictive content of carbon emissions for other climate risks and quantifying their potential effects as investors shift their expectations about the potential effects of climate change represent a fruitful area for future research.

A Robustness of Evidence Based on Portfolio Sorts

This section presents evidence that the conclusions based on portfolio sorts are robust to several variations to the way we construct the portfolios. First, as suggested in Fama and French (2008), we construct value-weighted instead of equally-weighted portfolios to check that our conclusions are not sensitive to volatile returns that characterize small firms. As shown in A.1, consistent with our evidence based on equally-weighted portfolios, the return on a portfolio comprised of *A-rated* firms does not perform any better that of a portfolio with firms that have a score *C & below*. Similarly, the results in A.2 confirm our finding that firms with low CO_2 intensity increase in value and firms with a high CO_2 intensity decrease in value in response to the carbon tax news. The return spread for value-weighted portfolios sorted on carbon intensity is positive and statistically significant on the day the carbon tax increase was announced for both CAPM-adjusted and Fama French-adjusted returns.

In Table A.3 we explore if our evidence that environmental scores do not capture a firm's exposure to transition risk from climate change is independent on the provider of environmental scores. In particular, we use environmental scores provided by the Carbon Disclosure Project, RobecoSAM, and S&P IQ. Portfolios sorted on environmental scores from all three of these providers yield results that are consistent with our results in Section 3.1. The return spread between the *A-rated* portfolio and *C-rated & below* portfolio for all three scores is not statistically distinguishable from zero, for both CAPM-adjusted and Fama French-adjusted returns.

In the same spirit, we explore if our conclusion that CO_2 intensity is a good predictor of a firm's exposure to climate risk is robust to alternative definitions of carbon emissions intensity. Table A.4 shows that the log of CO_2 emissions and CO_2 intensity defined as the ratio of CO_2 emissions to the market value of a firm the year before the carbon tax news are both negatively related to the change in value of the portfolios in response to the unexpected increase in the carbon tax.

Table A.1: Risk-Adjusted Returns on Value-Weighted Portfolios Sorted on Environmental Score On December 16

	A-rated	B-rated	C-rated & below	A-rated minus C-rated
CAPM-adjusted	-0.17	0.21	0.57	-0.74
				[-1.22, -0.23]
Fama French-adjusted	-0.59	-0.23	0.23	-0.82
				[-1.34, -0.28]
Portfolio Characteristics				
	A-rated	B-rated	C-rated & below	
No. of Stocks	35	30	50	
ln CO_2 emissions	16.17	14.77	13.28	
CO_2 intensity	11.17	11.93	11.31	
Refinitiv E-score	0.91	0.66	0.38	
ln Market value	25.72	23.57	22.70	
ln Total assets	24.15	22.76	21.83	

This table presents CAPM and Fama French-adjusted value-weighted returns on three portfolios around the carbon tax news sorted according to environmental scores. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019). The last column reports the return spread between the portfolios with the highest and lowest environmental scores and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

Table A.2: Risk-Adjusted Returns on Value-Weighted Portfolios Sorted on Carbon Emissions Intensity On December 16

	Low emitters	Neutral	High emitters	Low minus High
CAPM-adjusted	0.51	-0.22	-0.27	0.78
	(0.32)	(0.31)	(0.18)	(0.36)
				[0.06, 1.26]
Fama French-adjusted	0.11	-0.64	-0.71	0.81
	(0.30)	(0.30)	(0.19)	(0.36)
				[0.15, 1.33]
Portfolio Characteristics				
	Low	Mid	High	
No. of Stocks	34	46	35	
ln CO_2 emissions	11.51	13.22	16.36	
CO_2 intensity	6.79	9.74	13.31	
Refinitiv E-score	0.58	0.59	0.67	
ln Market Value	23.20	23.42	23.09	
ln Total assets	25.44	24.20	23.77	

This table presents CAPM and Fama French-adjusted value-weighted returns on three portfolios around the carbon tax news sorted according to carbon emissions intensity. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019). The last column reports the return spread between the portfolios with the highest and lowest emissions intensity and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

Table A.3: Risk-Adjusted Returns on Portfolios Sorted on Environmental Score On December 16

	A-rated	B-rated	C-rated & below	A-rated minus C-rated
	Panel A: Carbon Disclosure Project			
CAPM-adjusted	-0.07	0.21	0.25	-0.33
	(0.24)	(0.25)	(0.43)	(0.50)
				[-1.15, 0.51]
Fama French-adjusted	-0.50	-0.24	-0.11	-0.39
	(0.24)	(0.28)	(0.44)	(0.50)
				[-1.25, 0.37]
	Panel B: RobecoSAM			
CAPM-adjusted	-0.09	-0.09	-0.38	0.29
	(0.24)	(0.24)	(0.49)	(0.55)
				[-0.58, 1.22]
Fama French-adjusted	-0.51	-0.57	-0.90	0.39
	(0.26)	(0.24)	(0.56)	(0.60)
				[-0.56, 1.42]
	Panel C: S&P			
CAPM-adjusted	-0.29	0.20	0.34	-0.63
	(0.26)	(0.26)	(0.60)	(0.65)
				[-1.62, 0.52]
Fama French-adjusted	-0.72	-0.23	-0.12	-0.60
	(0.27)	(0.27)	(0.62)	(0.68)
				[-1.55, 0.69]

This table presents CAPM and Fama French-adjusted value-weighted returns on three portfolios around the carbon tax news sorted according to environmental scores. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019). The last column reports the return spread between the portfolios with the highest and lowest environmental scores and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

Table A.4: Risk-Adjusted Returns on Portfolios Sorted on Carbon Emissions and Emissions Intensity On December 16

	Low emitters	Neutral	High emitters	Low minus High
	Panel A: Carbon emissions			
CAPM-adjusted	0.75	0.06	-0.16	0.92
	(0.35)	(0.25)	(0.17)	(0.39)
				[0.26, 1.57]
Fama French-adjusted	0.33	-0.36	-0.56	0.89
	(0.36)	(0.24)	(0.17)	(0.40)
				[0.20, 1.52]
	Panel B: Carbon emissions intensity (market value)			
CAPM-adjusted	0.39	0.50	-0.40	0.79
	(0.26)	(0.26)	(0.26)	(0.38)
				[0.18, 1.38]
Fama French-adjusted	-0.07	0.09	-0.77	0.70
	(0.29)	(0.27)	(0.25)	(0.37)
				[0.04, 1.28]

This table presents CAPM and Fama French-adjusted equally-weighted returns on three portfolios around the carbon tax news sorted according to carbon emissions and carbon emissions intensity computed as the ratio of carbon emissions to market value. Portfolio returns are presented for the day the carbon tax increase is announced (December 16, 2019). The last column reports the return spread between the portfolios with the highest and lowest emissions and, in brackets, its associated 90 percent confidence interval. The confidence intervals are obtained using a bootstrap methodology with 1000 samples.

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