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Climate transition risk, profitability and stock prices

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ABSTRACT

We investigate whether climate transition risk is reflected in the financial performance and cross-section pricing of publicly-traded European and US firms. Using a firm-level carbon risk score (CRS) that assesses the vulnerability of a firm's value to transition to a low-carbon economy, we find that firms with the lowest transition risk exposures perform better financially, and that European firms are more sensitive to transition risks than US firms. We also find that stocks with low exposure to transition risk offer greater returns to investors, consistent with the fact that stock prices of firms do not adequately reflect underlying climate transition risk. Relative financial performance of less vulnerable firms and underreaction effects to transition risk decreased after COP21.

1. Introduction

In recent years investors' concerns regarding climate change risks have soared. Recent research has documented that climate change risks are an essential ingredient in investment decision-making by private and institutional investors (Krueger, Sautner, & Starks, 2019; Reboredo & Otero, 2021) and in the pricing of financial assets (e.g., Bolton & Kacperczyk, 2021; Ilhan, Sautner, & Vilkov, 2020; Monasterolo & De Angelis, 2020). Climate change risks to firm values take the form of natural disasters (*physical risk*), and regulatory, technological or consumer preference changes affecting actions to limit carbon emissions in moving towards a greener economy (*transition risk*). While the effects of natural disasters on firm values can be quantified based on each firm's exposure when the risk materializes, transition risks are more pervasive as they depend on the way each firm internalizes the costs associated with climate change over a long period of time.

In this study, we aim to explore whether and how transition risk is reflected in the profits and cross-section stock returns of firms. Addressing this issue requires measuring the firm's exposure to transition risk. We use rated information on individual firms' exposure to transition risk as reported by Sustainalytics — a widely recognized leading provider of environmental, social and governance (ESG) information. This rating, called the carbon risk score (CRS), provides a measure of transition risk at the firm level, annually computed on the basis of the exposure and management of transition risk across the firm's supply chain, operations, products and services. The firm's unmanaged transition risk is rated with a CRS between 0 and 100: negligible (0), low (1 to 9.99), medium (10 to 29.99), high (30 to 49.99) or severe (50 or more).[1] As a transition risk measure, the CRS metric provides deeper insights than the carbon footprint metric or the information reported for ESG factors, as the CRS specifically evaluates the risk for the firm's economic value entailed by the transition to a low-carbon economy. A distinctive feature of the CRS metric is that it internalizes the cost of the carbon externality by scoring its impact on the firm's value. It therefore reports useful information that enables stakeholders to internalize the economic cost of the carbon externality.

We specifically examine how annual information on the CRS metric impacts on future profitability and stock return performance for a sample of publicly-traded European and US firms over the period 2013–2018. To that end, for each market and time t we sort firms based on their CRS into quintiles, i.e., firms with the lowest transition risk exposure in the lowest quintile and firms with the highest transition risk exposure in the highest quintile. We then focus on the spread in future profitability and stock return performance of firms in those quintiles

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[1] https://www.sustainalytics.com/

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using both portfolio-level analyses and cross-section regressions.

The empirical evidence shows that firms with the lowest exposure compared to those with the highest exposure perform better in terms of returns on assets (ROA), returns on equity (ROE), earnings before interest, tax, depreciation and amortization (EBITDA) and Tobin's q ratio. We also find that European firms exhibit greater sensitivity to transition risk, while only the most exposed US firms experience a significant deterioration in profitability. Further, in terms of risk pricing, our evidence suggests that markets underreact to transition risks as embedded in the Sustainalytics CRS ratings, given that (a) excess returns and risk-adjusted returns for a long-short trading strategy in the first and fifth quintile portfolios, respectively, and (b) Fama and MacBeth (1973) cross-section regressions indicate that reducing transition risk has a favourable impact on future stock returns at the portfolio and firm levels. This is consistent with the idea that markets under-price transition risks; i.e., markets have not fully embedded this kind of risk into asset prices. Likewise, this evidence is also consistent with consumption-based capital asset pricing models with climate uncertainty, where investors demand a positive (negative) risk premium to hold assets with low (high) exposure to climate transition risk, given that those assets do not provide an insurance against consumption shocks arising from climate change risks. Finally, our empirical findings are consistent with the evidence documented by Hong, Li, and Xu (2019), who report that food stock prices underreact to climate change risk as measured by food stock exposure to drought risk, and also by Goldsmith-Pinkham, Gustafson, Lewis, and Schwert (2021), who report that prices in municipal bonds do not fully reflect climate risks.

We next investigate whether, after COP21 (the 2015 United Nations Climate Change Conference, held in Paris, 30 November to 12 December 2015), investors' sensitivity to transition risk was raised, driving investors to reassess climate risks to the extent that the expected effects of climate change should be reflected in firm values and, consequently, may be reflected in a change in the spread in profitability and stock return performance between firms that are less and more vulnerable to transition risk. We run a difference-in-differences (DiD) analysis that indicates that, after COP21, the spread between firms with high and low transition risk exposure narrows. However, differences are evident in European and US markets: in European markets, investors correct underreaction by reducing (increasing) the value of companies with high (low) transition risk exposure, while in the US markets, the return spread between less and more vulnerable firms remains with positive values.

Our findings have two key implications. First, they suggest that information on transition risks should be more widely disseminated in order to encourage suitable incentives to channelling financial resources into climate change mitigation. Our evidence consistently indicates that, as European investors' post-COP21 climate awareness increases, underreaction effects are corrected. Second, our findings suggest that a metric, such as CRS, that informs investors on the impact of transition risks on firm values is useful for the design of portfolios and for managing risk in a way that exploits the benefits of the transition to a low-carbon economy. In addition, information on transition risks as reported by the CRS is also useful for climate policies: while climate transition risk is an aggregate risk, heterogeneity in exposure across different firms provides risk-sharing opportunities that could be exploited in climate transition policies. Overall, CRS information is useful to address important dimensions of climate change economics that are financial in nature: those related to pricing and hedging risk from climate change, and those related to the effects of climate change risk on investor decision-making.

The remainder of the paper is laid out as follows. In Section 2 we develop the main hypotheses and comment on the related literature. Section 3 describes the CRS metric, data for European and US firms and the corresponding descriptive statistics. Section 4 examines the impact of transition risk on the performance of firms using portfolio sorts and firm-level regressions. Section 5 explores whether the climate transition risk is efficiently priced in stock markets through portfolio-level and cross-section regression analyses. Section 6 explores, through a DiD analysis, how COP21 impacts on the profitability and stock return performance of firms with low and high transition risk exposure. Section 7 provides a robustness analysis. Finally, Section 8 concludes our analyses.

2. Hypothesis development and related literature

2.1. Hypotheses

Climate transition risk has to do with the potential impact of the transition to a low-carbon economy on a firm's value. The vulnerability of firm values to transition risks stems from three different sources: (a) policy changes to adapt the economy to a low-carbon setup (e.g., stringent carbon-pricing policies to limit emissions, stricter energy efficiency standards); (b) technological changes (e.g., the introduction of more competitive low-carbon technologies); and (c) changes in consumer preferences (e.g., environmentally concerned consumers tilting their decisions towards sustainable products). The transition process involves costs that can affect firm payoffs, production costs and the repricing of stranded fossil fuel assets, ultimately affecting the equity and debt values of firms. The potential impact of transition to a low-carbon economy largely depends on a firm's exposure to transition risk, the management of such risk and the speed of the adjustment towards a greener economy.

This study examines the implications of transition risk along two axes: the firm's financial performance and stock price returns. Evidence on the impact of transition is still scarce, as the effects of this transition, already presumably underway, will only be manifested over a lengthy period of time. However, there is some evidence that transition can impact on a firm's decisions and performance. Bernardini, Di, Faiella, and Poli (2021) show that European electrical companies increased their investment in renewable energies after the EU adopted policies to support the use of renewables. Huang, Punzi, and Wu (2019) show that the Clean Air Action promoted by the Chinese government in 2013 increased default rates of polluting firms, while Cui, Geobey, Weber, and Lin (2018) document that Chinese banks with lower loan exposure to polluting firms have better non-performing loan rates. Garvey, Iyer, and Nash (2018) show that a low-carbon emission rate is associated with improved future profitability of firms. On the basis of this previous evidence, we conjecture that, as the transition risk materializes across different dimensions, firms with lower exposure to transition risks can be expected to be more profitable than highly exposed firms. We thus propose the following hypothesis.

H1. *: There is a negative relationship between a firm's climate transition risk and a firm's profitability.*

We test this hypothesis (a) using portfolio analysis, sorting firms into different portfolios according to their transitions risk ratings, and (b) using firm-level regression of the individual firm's profitability on information of climate risk exposure and a set of control variables. Specifically, we test whether a firm's exposure to transition risk is useful to predict future profitability. If the null hypothesis holds, this will indicate that the effects of transition are already being reflected in the outcomes of the firm's activity. However, if H1 is rejected, this means that climate transition risk is not yet salient; either the transition process is not being materialized or it is expected to have no effects on firm's activity, buffering thus the adverse effects of progressive transition to the new setup.

We next examine the impact of transition risk on asset returns, which could operate through different channels. Asset pricing theory suggest that the firm's value increases with future expected payoffs; thus, if H1 holds, then the stock price of firms with lower exposure to transition risk should be greater than the price of firms of similar characteristics but higher exposure.

However, as for any kind of risk, investors require a premium to assume transition risks. Therefore, companies with high exposure to risk are expected to pay investors higher stock returns (a carbon risk premium) in compensation for the higher exposure of investors. Some empirical research that uses carbon emissions as a proxy for transition risks documents the existence of this carbon premium (e.g., Bolton & Kacperczyk, 2021; Hsu, Li, & Tsou, 2022; Oestreich & Tsiakas, 2015). Likewise, this carbon risk premium could also emerge as a result of the lower returns accepted by climate-aware investors for investments not affected by transition risks. For European firms, Alessi, Ossola, and Panzica (2021) provide evidence of a negative carbon risk premium for firms with low greenhouse emissions and high environmental quality.

The impact of transition risk on stock prices also depends on how that risk impacts on discount factors. For the housing market, Giglio, Maggiori, Rao, Stroebel, and Weber (2018) shows that the term structure of discount rates is downward-sloping and that cash flows are more exposed to climate risk in the short- than in the long-run. Consistently, the effects of transition risks should be reflected in asset prices through this channel.

Finally, although the transition to a low-carbon economy has indisputably favourable (unfavourable) effects on investments that mitigate (exacerbate) climate change, how this transition impacts consumption is crucial to determining the sign of the risk premium of assets with low or high exposure to climate transition risk. The consumption-based capital asset pricing model (CAPM) states that investors are willing to accept lower asset returns when those returns covary negatively with consumption (Breeden, 1979; Lucas, 1978). Thus, when the driver to the transition to a greener economy is uncertainty about economic growth (Giglio, Kelly, & Stroebel, 2021; Lemoine, 2020), higher growth and consumption levels are associated with greater climate effects. Hence, mitigating climate change investments (those with lower transition risks) generates greater payoffs when consumption levels are higher, so additional consumption is less valuable. Therefore, investors demand a positive (negative) risk premium for assets with low (high) exposure to climate transition risk. Contrarily, when the driver to transition to a greener economy is uncertainty about the climate, climate change events negatively impact on consumption, and when consumption is low, investments with low transition risk yield higher payoffs. Thus, investors are willing to accept a negative risk premium to hold assets with low exposure to climate transition risk, as those assets act as insurance against negative consumption shocks.

On the basis of previous arguments, there is no clear impact of transition risk on stock price returns, as different channels and models suggest different kinds of impact in sign and size. Therefore, the ultimate impact of transition risk is an empirical issue that depends on the predominant effects of each of the channels commented above. As investors become increasingly concerned with transition risk but do not fully oversee the financial performance of their investment decisions (Monasterolo & De Angelis, 2020), we conjecture that the stock returns of firms with low transition risk will be greater than the stock returns of firms with a high transition risk. We thus propose the following hypothesis.

H2. *: The stock returns of firms exposed to low transition risk are greater than the stock returns of firms exposed to high transition risk.*

This hypothesis is consistent with the asset pricing theory that suggest that a firm's value increases with future expected payoffs, and with a positive risk premium for mitigating investments that stems from climate models in which uncertainty regarding climate change comes from the path of the economy. Likewise, this hypothesis is also consistent with the equilibrium model of Pástor, Stambaugh, and Taylor (2021) that states that green or low carbon transition risk assets offer greater realized returns than brown or high carbon transition risk assets when an agent's tastes shifts in the green direction.

As for H1, we test H2 using portfolio analysis and firm-level regressions. If H2 holds, the expected effects of the transition process will be reflected in the market value of firms. However, markets underreact to transition risks if firms with higher risk exposure do not offer suitable compensation for the assumption of transition risk, i.e., investors are not efficiently pricing transition risks.

2.2. Related literature

Our study is related to the burgeoning literature on the impact of climate-related risk on financial markets (Hong, Karolyi, & Scheinkman, 2020), in particular that related to profitability and stock return performance and firm values. Specifically, in considering the impact of transition risk on profitability and stock return performance, our study corresponds to the literature that examines the asset pricing effects of climate-related risks. Within the framework of rational asset pricing, Bansal, Kiku, and Ochoa (2016) document that global warming, proxied by temperature fluctuations, is embedded in market prices. Similarly, Giglio et al. (2018) show that real estate is exposed to climate risk. In contrast, Hong et al. (2019) find that stock prices of food firms deviate from purely rational pricing, as food companies in countries with higher exposure to drought risk exhibit poorer profitability and stock return performance, consistent with stock price underreactions to climate change risks.[2] Our paper, in contributing to this literature by documenting market underreactions to climate transition risks, differs from previous studies in considering a general set of firms representing different economic sectors and in our use of the specific CRS measure of transition risk that informs on the vulnerability of firm values to the transition to a low-carbon economy.

Our research also fits with studies examining the impact of climate-related risk on portfolio performance. Andersson, Bolton, and Samama (2016), in examining a dynamic investment strategy that allows passive investors to hedge climate-related risk without sacrificing financial returns, find that the tracking error can be virtually eliminated even for a low-carbon index with 50% less of a carbon footprint than its benchmarks. Jong and Nguyen (2016) show how bond investors can hedge portfolios against climate-related risk without introducing unintended exposure that could sacrifice the portfolio's benchmark-tracking properties. BlackRock (Economist, 10 September 2016, p. 61) show that it is possible to create a portfolio comprised of companies with carbon emissions 70% lower than in the overall market that achieve an annual market tracking error of just 0.3%.

Other research describes the effects of fossil fuel stock divestment on portfolio performance. Trinks, Scholtens, Mulder, and Dam (2018), in comparing the financial performance of investment portfolios with and without fossil fuel stocks, report that fossil fuel divestment does not seem to impair portfolio performance; this is because fossil fuel stocks do not outperform other stocks on a risk-adjusted basis and also provide relatively limited diversification benefits. Reboredo and Otero (2021, 2022) show that fund investors consider climate-related transition risk to be an undesirable fund feature and, accordingly, allocate more money to funds with lower climate-related transition risk. For pension funds, Boermans and Galema (2019) show that funds that deviate from market benchmark weighting to reduce carbon exposure do not show impaired risk-adjusted performance. More recently, Engle et al. (2020) document how to implement a dynamic portfolio hedging strategy to hedge risk with respect to a climate risk news index built through textual analysis of the *Wall Street Journal*; using the same news index, Huynh and Xia (2021) report that corporate bonds exposed to climate risk news yield lower future returns and that investors are willing to pay higher prices

[2] Other climate-related events, such as flooding risk, were shown to have mixed effects. Bernstein, Gustafson, and Lewis (2019), Ortega and Taspinar (2018) and Murfin and Spiegel (2020) find that coastal homes vulnerable to sea level rise are priced at a discount relative to similar homes at higher elevations, whereas Baldauf, Garlappi, and Yannelis (2019) and Bakkensen and Barrage (2018) report weak evidence on the impact of the same risk on coastal house prices.

for bonds issued by firms with a good environmental profile. Likewise, using textual analysis, Berkman, Jona, and Soderstrom (2019) find that their climate-related risk measure is negatively related to the value of firms. Our research contributes to that literature, first, in using the CRS transition risk measure, which is based on ratings regarding the impact of the transition to a low-carbon economy on a firm's value, and second, in documenting that portfolios comprised of firms with low transition risk exposure offer higher returns and so are attractive for investors.

Our study also adds to the literature covering the impact of carbon emissions on firm values and returns. Some studies document that firms with higher emissions also display lower firm values and higher costs of capital (Chava, 2014; El Ghoul, Guedhamib, Kwok, & Mishra, 2011; Ginglinger & Moreau, 2021; Matsumura, Prakash, & Vera-Muñoz, 2014). Other studies focusing on the effects of carbon emissions on stock and portfolio returns report mixed results. Bolton and Kacperczyk (2021) find that carbon emissions as measured by Greenhouse Gas Protocol (GGP) Scopes 1, 2 and 3 have a positive impact on a cross-section of US stock returns, which can be understood as additional compensation for transition risk exposure. In a similar vein, Hsu et al. (2022) examine the effects of environmental pollution on a cross-section of stock returns, finding that highly polluting firms – more exposed to environmental regulation risk – command higher average returns. For a sample of German firms, Oestreich and Tsiakas (2015) show that firms with high carbon emissions have higher transition risk exposure and exhibit higher expected returns. Likewise, Trinks, Mulder, and Scholtens (2020) document that carbon-efficient firms display greater profitability and lower systematic risk, while Horváthová (2010, 2012) document that the relationship between environmental and financial performance may differ between the short and long run. Görgen et al. (2019), using brown minus green portfolios, quantify climate-related risk in order to estimate a carbon beta for firms and thus capture firm sensitivity to the transition to a low-carbon economy. Using low-carbon and carbon-intensive indices, Monasterolo and De Angelis (2020), in the post-COP21 scenario, report evidence consistent with the fact that investors appreciate low-carbon assets but do not fully disregard carbon-intensive assets. On the other hand, in examining a low-carbon efficient portfolio in terms of greenhouse gas emissions, In, Park, and Monk (2019) report that efficient portfolios generate abnormal returns of 3.5%–5.4% per year. Also, for a sample of global stocks, Garvey et al. (2018) document a positive impact of a low-carbon emission rate on future profitability and stock returns. Similarly, Choi, Gao, and Jiang (2020) show that high-carbon firms underperform low-carbon firms during extreme heat events. Considering downside risk, Ilhan et al. (2020) find that carbon emissions increase that risk, and that this effect increased after COP21. Consistent with those negative effects of carbon emissions, we find that increased transition risk exposure has a negative effect on the profitability and stock return performance of firms and that this effect is moderated in the post-COP21 scenario.

3. Data

To address the issue of whether and how transition risk impacts on financial performance and price returns of firms, we firstly sourced data from Sustainalytics at the firm level on firms' transition risk. On an annual basis, Sustainalytics rates firms with a CRS between 0 and 100, where lower numbers represent lower transition risk exposure. A CRS is assigned to each firm on the basis of their exposure to and management of risk. Exposure evaluates to what extent the firm's supply chain, its operations and product and services are exposed to carbon risks (largely determined by the firm's type of business). Carbon-risk exposure is measured at the subindustry level, for 146 subindustries with different intrinsic degrees of exposure. Thus, each firm is assumed to have carbon exposure that corresponds to its subindustry, but specific adjustments are made by firms to account for deviations from subindustry values (e.g., financial strength, geographical location, regulations of firm's activities). Management accounts for a firm's ability to deal with carbon risks and reduce carbon emissions through policies, programmes and systems applied to operations and to the development of greener products and services. Unmanaged risk is the risk over which the company has no control and those manageable risks that have not been addressed by the firm. The CRS reflects the unmanageable carbon risk that remains, despite management actions designed to diminish transition risk exposure.[3]

The distinctive feature of CRS data is that it not only considers GGP Scope 1, 2, and 3 carbon emissions, but also all strategic actions designed to manage the impact of the transition to a low-carbon economy on the firm's value. According to the CRS, firms can be categorized as having: (a) negligible transition risk (CRS values of 0): the company has little or no material risk in a low-carbon economy; (b) low transition risk (CRS values of 1 to 9.99): the company could be impacted by carbon risks if those risks are not appropriately managed; (c) medium transition risk (CRS values of 10 to 29.99): the company is exposed to carbon risks that might make it a market underperformer if those risks are not addressed; (d) high transition risk (CRS values of 30 to 49.99): the company has highly material carbon risks that will make it a laggard in the market if those risks are not addressed; and (e) severe transition risk (CRS values of 50 or more): the company is unlikely to survive in a low-carbon economy.

CRS ratings are available to investors, so these can assess firms in terms of their transition risk. Moreover, institutional and private investors can also evaluate whether climate transition risk poses a greater or lesser financial threat to the value of their fund portfolios on the basis of the Morningstar portfolio CRS. Morningstar computes, and makes readily available to investors, the fund portfolio CRS of a global universe of some 30,000 funds based on Sustainalytics company-level evaluations of climate transition risk.[4] As reported by Reboredo and Otero (2021), transmitting transition risk information may help investors adopt more resilient investment and risk management strategies.

Our database includes all European and US firms rated with a CRS by Sustainalytics between 2013, when CRS started to be computed at the firm level, and 2018. Since we use market information in our analysis, we focus only on firms listed over the sample period, i.e., 939 European and 830 US firms out of totals of 951 and 868, respectively. Companies included in our sample account for 99.4% and 94.5% of firms included in the Eurostoxx-600 and the S&P indices, respectively, and for the 97% and 96% of their market capitalization, respectively, at the end of 2018. The panel of firms is unbalanced as we have no market information for some firms for the whole period 2013–2018 (totalling 5382 and 4783 annual observations for European and US firms, respectively).

We use balance-sheet and market information for 2013–2018 for the firms included in our sample, specifically, annual balance-sheet data from Thomson Datastream on profitability as measured by ROA, ROE and EBITDA in relation to total assets. As a measure of performance, we also use annual information on Tobin's q ratio.

In examining the impact of transition risk on a firm's profitability, we control for firm characteristics widely acknowledged in the literature to be related to profitability (see, e.g., Fama & French, 1993; Chava, 2014; El Ghoul et al., 2011), as follows: firm size, measured as the natural logarithm of the book value of total assets; leverage, measured as debt over total assets; sales over total assets; dividend payments, measured by an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise; and average price-to-book value, defined as the firm's market price per share over the book value per share. To mitigate the impact of outliers, profitability and control variables are winsorized at the 1% and 99% levels when their values are smaller (greater) than their

[3] For further information on the methodology to compute CRS values, see https://www.sustainalytics.com/ and https://www.morningstar.com/lp/low-carbon-economy.

[4] See https://www.morningstar.com/content/dam/marketing/shared/Company/LandingPages/CarbonRisk/Carbon_Risk_Paper.pdf?cid=EMQ_

Table 1
Descriptive statistics.

Panel A. European firms								
	Mean	Median	St. Dev.	p10	p25	p50	p75	p90
CRS	11.489	10.573	9.415	0.000	4.453	10.573	16.790	23.400
ROA	6.275	5.505	8.068	0.358	2.370	5.505	9.159	14.669
ROE	14.240	12.817	19.652	−0.097	6.876	12.817	20.104	31.337
EBITDA/TA	10.976	10.246	9.594	1.173	5.951	10.246	14.831	21.507
Tobin's q	1.918	1.423	1.497	0.978	1.067	1.423	2.082	3.327
Size	15.986	15.782	1.993	13.602	14.578	15.782	17.298	18.620
D/TA	24.311	23.240	17.777	1.146	10.900	23.240	34.890	47.480
S/TA	0.693	0.605	0.574	0.054	0.253	0.605	0.968	1.399
Dividends	0.873	1.000	0.333	0.000	1.000	1.000	1.000	1.000
M/B	6.996	2.378	36.359	0.882	1.317	2.378	4.047	7.315
Annual returns	6.260	7.219	31.487	−30.317	−9.961	7.219	23.338	40.105

Panel B. US firms								
	Mean	Median	St. Dev.	p10	p25	p50	p75	p90
CRS	13.706	11.406	14.204	0.000	0.405	11.406	19.181	28.774
ROA	6.211	5.621	7.109	0.593	2.636	5.621	9.603	14.588
ROE	18.361	13.375	31.618	−0.970	7.060	13.375	22.861	38.945
EBITDA/TA	11.803	11.014	8.834	1.922	6.859	11.014	16.355	22.778
Tobin's q	2.265	1.730	1.585	1.035	1.248	1.730	2.622	4.223
Size	16.211	16.029	1.433	14.573	15.244	16.029	17.055	18.092
D/TA	29.827	28.928	20.029	3.853	14.963	28.928	41.874	54.073
S/TA	0.690	0.535	0.648	0.089	0.248	0.535	0.884	1.486
Dividends	0.735	1.000	0.441	0.000	0.000	1.000	1.000	1.000
M/B	8.809	3.105	36.168	1.185	1.842	3.105	5.494	10.916
Annual returns	8.083	9.607	28.876	−26.274	−6.443	9.607	24.963	39.424

This table shows summary statistics (mean, median, standard deviation and percentiles) for the variables used in our study. Panels A and B report results for the variables indicated in the first column for European and US firms, respectively. CRS is the annual low-carbon risk rating as reported by Sustainalytics; ROA is the annual return on assets; ROE is the annual return on equity; EBITDA/TA are annual earnings before interest, tax, depreciation and amortization scaled by total assets; Tobin's q is the annual ratio between the market value of the firm over its asset replacement cost; Size is the natural logarithm of the book value of total assets; D/TA is annual total debt over total assets; S/TA are annual sales over total assets; Dividends is an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise; M/B is the annual ratio between the market price per share over book value per share for the firm; finally, Annual returns are the firm's annual market returns. The sample covers annual periods from 2013 to 2018.

average values plus (minus) four times their standard deviation. Finally, for each firm, we also use market information on daily and monthly stock market prices and trading volumes, sourced from Bloomberg.

Table 1 shows descriptive statistics for the European and the US markets for the variables we use in our study. The average climate transition risk rating is 11.4 for European firms but 13.7 for US firms, and the distribution of ratings across the CRS also differ, with the European distribution displaying lower skewness and a thinner upper tail. Fig. 1 displays the CRS distribution over the sample period, showing that the transition risk exposure of firms remains relatively stable over the sample period and that US firms are more exposed to transition risk — mainly extremely high CRS — than European firms. Visual inspection of Fig. 1 also reveals that the CRS distribution shifts to the left as the years go by, reflecting, thus, reduced average CRS. Descriptive statistics for performance variables reveal that firms obtain positive results of a greater average size and with a distribution shifted to the right for the US firms. Likewise, average size, price-to-book value, leverage and annual returns are greater for US than for European firms.

Table 2 reports average values for the profitability and control variables by climate transition risk categories. For European firms, average values of all profitability variables reveal that profitability decreases as transition risk exposure increases, so firms at severe risk are far less profitable than firms at negligible risk. Consistent with this fact, firms' returns decrease as the level of transition risk exposure increases. For US firms, however, profits remain similar for negligible, low and medium categories of risk, although they decline sharply for firms in the severe risk category. Thus, the descriptive evidence shows that European and US firms exhibit different profitability features in relation to their transition risk exposure: as exposure increases, profitability decreases for European firms, while it remains constant for US firms, except at extremely high risk, when profitability drops. As for control variables, the price-to-book value of firms decreases with climate transition risk on both sides of the Atlantic, while there is no clear pattern for the remaining control variables.

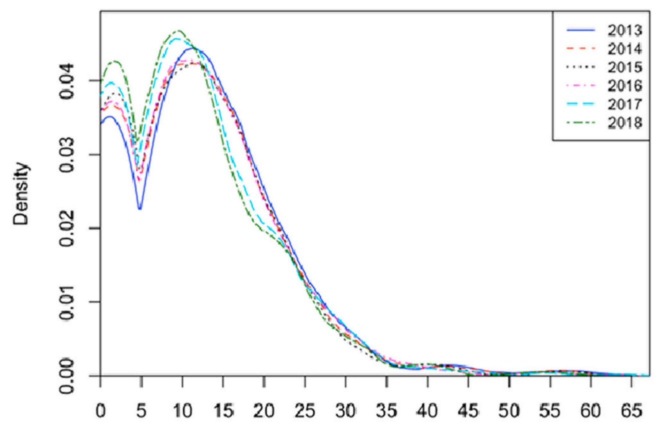
Table 3 shows the transition probabilities for different risk categories, showing high persistence within risk categories, with transition probabilities of zero between extreme risk categories. This evidence is consistent with the temporal stability of the CRS distribution displayed in Fig. 1.

Table 4 shows the distribution of firms across sectors, along with average values for transition risk and size. The distribution is unequal: most firms in Europe are in the industrial, financial and consumer staples sectors, while most firms in the USA are in the information technology, financial and industrial sectors. Firms in the energy, materials and utilities sectors exhibit the highest transition risk exposure in both the European and US markets, while firms in the healthcare and information technology sectors display the lowest transition risk exposure. As for size, average size by sector suggests that there are no major differences across sectors.[5]

4. Does a transition risk rating impact on a firm's profitability?

In this section, we examine whether the CRS provides information on future firm profitability. Using portfolio sorts and firm-level regressions, we show that firms with lower transition risk exposure perform better than firms with higher transition risk exposure.

[5] For additional descriptive information, see the online Appendix.



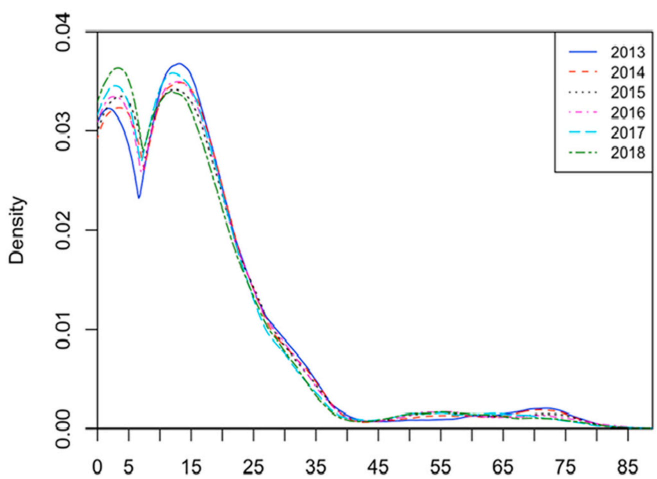


Fig. 1. Climate transition risk rating distribution.
This figure depicts the annual distribution of the climate transition risk for European (Panel A) and US (Panel B) firms. Non-parametric density is estimated using the Epanechnikov kernel. Panel A. European firms. Panel B. US firms.

Table 2
Climate transition risk and firm characteristics.

Panel A. European firms	Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk
ROA	8.298	6.783	5.431	2.896	1.420
	(10.38)	(7.47)	(7.08)	(7.88)	(6.48)
ROE	17.339	16.153	12.646	5.276	−3.671
	(23.04)	(17.73)	(18.60)	(21.85)	(21.29)
EBITDA/TA	14.335	11.352	9.536	9.019	6.567
	(12.28)	(9.31)	(8.00)	(9.28)	(9.58)
Tobin's q	2.832	1.923	1.595	1.252	1.138
	(2.03)	(1.39)	(1.15)	(0.55)	(0.21)
Size	15.179	16.405	15.996	17.023	17.242
	(1.65)	(2.17)	(1.88)	(2.41)	(1.05)
D/TA	23.449	23.139	25.212	25.791	27.002
	(21.62)	(17.51)	(16.27)	(14.90)	(15.67)
S/TA	0.806	0.705	0.635	0.736	0.786
	(0.65)	(0.61)	(0.52)	(0.42)	(0.72)
Dividends	0.808	0.944	0.864	0.812	0.750
	(0.39)	(0.23)	(0.34)	(0.39)	(0.44)
M/B	11.405	5.677	6.306	2.178	1.685
	(46.97)	(28.48)	(36.62)	(2.83)	(1.26)
Annual returns	10.510	6.934	4.475	2.433	−3.896
	(33.44)	(27.67)	(32.52)	(31.49)	(33.70)

Panel B. US firms	Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk
ROA	6.684	7.578	6.039	4.524	1.096
	(9.10)	(6.69)	(5.73)	(5.29)	(8.60)
ROE	19.233	26.165	17.393	8.433	0.556
	(34.29)	(40.13)	(26.91)	(18.96)	(19.31)
EBITDA/TA	12.983	13.154	11.072	10.126	9.250
	(10.63)	(9.08)	(7.63)	(5.88)	(9.97)
Tobin's q	3.081	2.476	1.899	1.554	1.418
	(2.00)	(1.77)	(1.13)	(0.56)	(0.54)
Size	15.813	16.585	16.231	16.445	16.417
	(1.42)	(1.60)	(1.36)	(1.26)	(1.04)
D/TA	27.550	32.377	29.632	34.454	28.512
	(20.69)	(23.23)	(18.79)	(18.45)	(11.86)
S/TA	0.748	0.736	0.654	0.674	0.555
	(0.59)	(0.70)	(0.66)	(0.51)	(0.76)
Dividends	0.507	0.817	0.814	0.884	0.660
	(0.50)	(0.39)	(0.39)	(0.32)	(0.48)
M/B	14.596	7.942	6.489	10.390	2.219
	(50.26)	(25.64)	(29.48)	(51.46)	(1.39)
Annual returns	11.892	8.092	7.721	5.603	−7.899
	(29.45)	(27.08)	(27.04)	(34.01)	(39.38)

This table shows average values and standard deviations (in parentheses) by climate transition risk category (negligible, low, medium, high and severe) for the variables used in our study. Panels A and B report results for the variables indicated in the first column for European and US firms, respectively. ROA is the annual return on assets; ROE is the annual return on equity; EBITDA/TA are annual earnings before interest, tax, depreciation and amortization scaled by total assets; Tobin's q is the annual ratio between the market value of the firm over its asset replacement cost; Size is the natural logarithm of the book value of total assets; D/TA is annual total debt over total assets; S/TA are annual sales over total assets; Dividends is an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise; M/B is the annual ratio between the market price per share over book value per share for the firm; finally, Annual returns are the firm's annual market returns. The sample covers annual periods from 2013 to 2018.

4.1. Portfolio performance analysis

As in Bali, Brown, and Tang (2017) and Hong et al. (2019), we conduct a portfolio sorting analysis to examine the impact of transition risk on performance. Thus, at the end of each year t we rank firms based on an ascending sort of their CRS values and group them into five quintile portfolios, with the first quintile (Q1) and the fifth quintile (Q5) composed of firms with the lowest and highest transition risk exposures, respectively. European firms in portfolios Q1 to Q5 have average CRS values of 0.02, 5.93, 10.80, 15.65 and 25.76, respectively, while the same figures for US firms are 0.02, 6.12, 11.61, 17.29 and 34.89, respectively. For each portfolio at year t we compute portfolio profitability as the equally-weighted[6] profitability of firms within that portfolio in the subsequent time horizons $t + 1$, $t + 2$ and $t + 3$.

Table 5 shows portfolio profitability as measured by ROA, ROE and EBITDA over total assets and Tobin's q ratio for the five quintile portfolios, and compares profitability differences between the Q1 and Q5 portfolios using different profitability measures. For both European and US firms, the evidence in Table 5 points to the fact that — independently of the performance measure and the time horizon — portfolios with lower transition risk exposure exhibit better financial performance than portfolios with higher transition risk exposure. For both European and US firms, the difference between performance for the Q1 and Q5 portfolios is positive and statistically significant for all analysed time

[6] We use equal weights to determine portfolio composition to prevent a single firm with large market capitalization from determining the behaviour of the quintile portfolio. Evidence for portfolios with weights given by market capitalization is similar to the evidence reported here and is available on request.

Table 3
Transition probabilities between climate risk according to CRS values.

Panel A. European firms	Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk
Negligible Risk	99.77	0.11	0.11	0.00	0.00
Low Risk	0.33	94.42	5.25	0.00	0.00
Medium Risk	0.09	6.18	93.28	0.45	0.00
High Risk	0.00	0.00	12.50	86.81	0.69
Severe Risk	0.00	0.00	0.00	10.00	90.00

Panel B. US firms	Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk
Negligible Risk	99.90	0.00	0.00	0.10	0.00
Low Risk	1.11	94.61	4.29	0.00	0.00
Medium Risk	0.21	4.08	94.80	0.90	0.00
High Risk	0.00	0.00	13.53	83.09	3.38
Severe Risk	0.00	0.00	0.00	4.97	95.03

For the sample period 2013 to 2018 and for European (Panel A) and US (Panel B) firms, this table reports transition probabilities between climate transition risk categories: negligible risk, low risk, medium risk, high risk and severe risk.

horizons, independently of the performance measure used. Therefore, our evidence indicates that firms that avoid transition risk exposure are also able to increase their profitability; this result holds for the three time horizons under analysis, although differences between the Q1 and Q5 portfolios decrease as the time investment horizon increases.

Interestingly, average values for portfolio performance across quintile portfolios reveal differences between European and US firms. For the three analysed time horizons, the profitability of European firms gradually decreases as transition risk exposure increases, whereas for US firms the average values of all profitability measures remain quite similar from Q1 to Q3 and sharply reduce for Q5. This evidence is consistent with the descriptive analysis reported in Table 2, and with the fact that US firms are not very sensitive to transition risks except when risk is extreme; in contrast, European firms exhibit greater sensitivity, as reflected in the fact that performance is gradually more affected by increasing transition risk exposure.

Table 6 shows the results of a portfolio analysis with portfolios composed of firms rated in one of the five Sustainalytics CRS categories (negligible, low, medium, high and severe risk). Consistent with the evidence reported in Table 5, for both European and US portfolios, firms with high and severe CRS risk values perform more poorly than firms with negligible and low CRS risk values. Remarkably, for most measures and time horizons, the profitability of European firms gradually decreases as the risk rating of the portfolio increases, and the t-statistic indicates that profitability differences between the Q1 and Q5 portfolios are positive and statistically significant. However, as with Table 5, we observe that the profitability of US firms remains similar across different risk categories and is considerably reduced for severe risk exposure. This evidence indicates that the sensitivity of firm's profits to transition risk differs in the two markets.

4.2. Firm-level regression analysis

In the previous portfolio analysis we impose no parametric restriction on the relationship between transition risk and future firm profitability; however, that analysis disregards cross-section information and fails to control for many factors that could simultaneously impact on the relationship. Here we examine whether the above-reported results hold at the firm level once the effects of lagged profitability and specific firm characteristics are taken into account. Specifically, for each profitability measure we run the following one-year horizon panel regression:

$$P_{i,t+1} = \mu + \beta \; q1_{i,t} + \theta \; P_{i,t} + \gamma \; X_{i,t} + \varepsilon_{i,t+1}, \qquad (1)$$

where the variable $P_{i,\,t+1}$ denotes the profitability measure of firm i at time $t+1$ (ROA, ROE, EBITDA over total assets or Tobin's q ratio), and $q1_{i,\,t}$ is an indicator function that takes the value 1 when firm i is included in the first quintile portfolio at time t, and 0 otherwise. The parameter β measures the impact on profitability of the transition risk exposure of firm i over the profitability of firms in Q2 to Q5. We control for persistence in performance by considering the lagged performance value and other controls included in the X vector, i.e., as defined above, firm size, leverage, firm i's sales over total assets, dividend payment policy, and firm i's price-to-book value. We also control for unobserved heterogeneity by cross-section and over time by including sectoral fixed-effects (FE) dummies (see Table 4 for sector classification), country-specific FE for the European countries) and year FE dummies. All control variables are lagged one year to mitigate potential reverse causality concerns, and standard errors are computed by double clustering at the firm and time levels (see Petersen, 2009).

Looking at Table 7 Panel A, the evidence, significant at the 1% level, shows that — independently of the performance measure used — low exposure to transition risk increases the profitability of European firms. Estimates for the coefficient for Q1 for ROA is 0.57 with a t-statistic of 4.48; this coefficient can be interpreted as the average difference in future ROA values between firms in Q1 and firms in the remaining quintiles. Columns (1–3) in Panel A show that the significance of this positive coefficient is independent of whether we consider sectoral or year FE or control variables in the regression. Similarly, evidence of the positive effect of transition risk exposure on future performance is reported for other profitability measures. Specifically, ROE and EBITDA over assets and Tobin's q ratio for firms in Q1 are significantly higher

Table 4
Firms by sectors and transition risk exposure.

	European firms			US firms		
	# of firms	CRS	Size	# of firms	CRS	Size
Consumer staples	140	7.272	15.355	114	6.691	15.941
Consumer discretionary	59	8.710	16.078	48	10.959	16.325
Energy	38	29.104	16.814	51	52.359	16.606
Financials	157	12.231	17.671	122	11.060	17.562
Healthcare	76	2.930	15.198	80	2.809	15.767
Industrials	180	14.025	15.705	119	18.720	15.786
Information technologies	79	4.045	14.404	125	3.963	15.678
Materials	79	17.858	15.811	56	20.027	15.766
Real estate	67	12.921	15.704	74	13.917	15.814
Telecommunications Services	24	10.544	16.573	8	14.809	17.618
Utilities	40	14.728	16.927	33	24.593	17.253

For the European and US markets, this table shows the number of firms in our sample by sector, along with average CRS value and firm size (natural log of the firm's book value). Annual data from 2013 to 2018.

Table 5
Profitability of portfolios sorted by firm CRS values.

Panel A. European firms

		Q1	Q2	Q3	Q4	Q5	Q1-Q5	t-statistic
(t,t + 1)	ROA	9.317	6.925	5.699	4.946	4.968	4.349	12.50
	ROE	26.368	18.994	13.070	12.514	13.077	13.290	13.70
	EBITDA/TA	15.378	11.369	9.725	8.639	9.708	5.670	9.46
	Tobin's q	3.172	1.977	1.747	1.512	1.569	1.603	13.74
(t,t + 2)	ROA	9.433	7.233	5.687	4.872	5.025	4.408	11.12
	ROE	26.178	20.762	12.552	11.550	14.413	11.764	10.61
	EBITDA/TA	15.447	11.642	9.735	8.536	9.723	5.724	8.46
	Tobin's q	3.210	1.987	1.736	1.532	1.547	1.663	12.58
(t,t + 3)	ROA	9.608	7.327	5.452	4.911	5.280	4.328	9.14
	ROE	23.202	18.584	11.709	11.892	13.575	9.627	8.29
	EBITDA/TA	15.538	11.572	9.510	8.615	10.115	5.424	6.77
	Tobin's q	3.157	1.910	1.726	1.527	1.519	1.638	10.82

Panel B. US firms

		Q1	Q2	Q3	Q4	Q5	Q1-Q5	t-statistic
(t,t + 1)	ROA	6.049	6.865	6.187	5.667	4.846	1.203	4.85
	ROE	18.854	24.720	18.343	17.747	13.485	5.369	7.24
	EBITDA/TA	12.766	13.274	10.735	10.671	10.915	1.851	3.44
	Tobin's q	3.107	2.918	2.181	1.774	1.691	1.416	12.51
(t,t + 2)	ROA	6.502	7.225	6.128	5.696	4.377	2.125	7.52
	ROE	19.789	26.529	18.801	18.491	13.158	6.632	7.74
	EBITDA/TA	12.810	13.411	10.594	10.646	10.230	2.580	4.37
	Tobin's q	3.071	2.911	2.176	1.782	1.689	1.382	10.94
(t,t + 3)	ROA	6.987	7.622	6.183	5.712	5.140	1.847	5.07
	ROE	21.082	28.472	18.726	18.517	16.239	4.843	4.34
	EBITDA/TA	13.139	13.700	10.523	10.602	11.133	2.006	2.78
	Tobin's q	3.086	2.943	2.171	1.807	1.693	1.392	9.43

For quintile portfolios sorted by CRS values for firms, this table shows profitability as measured by the annual return on assets (ROA), the annual return on equity (ROE), annual earnings before interest, tax, depreciation and amortization scaled by total assets (EBITDA/TA), and Tobin's q (the annual ratio between the market value of the firm over its asset replacement cost). Firms are sorted by quintiles at the end of year *t* based on their CRS, from quintile 1 (Q1) — firms with the lowest transition risk exposure — to quintile 5 (Q5) — firms with the highest transition risk exposure. The portfolio holds for 1-year, 2-year and 3-year future periods following the portfolio configuration. Reported values are average profitability over the sample period from 2013 to 2018. Q1-Q5 denotes the difference in profitability between the low and high transition risk portfolios, with the t-statistic indicating the statistical significance of that difference.

than for firms in higher quintiles; this effect is likewise robust to the inclusion of sectoral and time effects and to the inclusion of control variables. As for control variables, the parameter estimates indicate that the price-to-book value and dividend payments have a positive impact on future performance, and that sales also have a positive impact on performance measures, with the exception of Tobin's q. Size, in contrast, has a significant negative effect, except for ROE.

Table 7 Panel B shows that, for US firms, transition risk exposure does not enhance profitability. For all measures of profitability, the coefficients estimated for Q1 are not significant, indicating that there is no difference in future performance between Q1 firms and other quintile firms. This evidence, consistent with the descriptive results reported in Table 2 and the portfolio analysis in Table 6 Panel B, points to no performance differences between US firms according to transition risk exposure, except for firms with high or severe risk exposure. Estimation results for the control variables show that profitability is negatively affected by size (except for ROE) and positively affected by sales (except for Tobin's q), price-to-book value and dividends (except for EBITDA).

Finally, Table 8 shows regression results as per Eq. (1) but considering the lowest risk portfolio comprised of firms with zero CRS. Empirical results point to similar conclusions to those reported in Table 7, i.e., low transition risk exposure has positive effects on the profitability of European firms but has no significant impact on the profitability of US firms.

5. Does a climate transition risk rating impact on stock returns?

Here we explore whether the climate transition risk is efficiently priced in stock markets by conducting portfolio-level and cross-section regression analyses based on stock return information.

5.1. Portfolio sorts

We examine whether climate transition risk is efficiently priced in stock markets by considering the relative return performance of portfolios with different risk exposure levels. On the basis of annual CRS information released for the year *t*, we sort firms into five quintile portfolios (Q1 to Q5). We then compute monthly portfolio returns as the equally-weighted average monthly stock returns of the firms in the corresponding quintile portfolio.[7] The composition of the monthly quintile portfolios remains constant through the year $t + 1$ and is updated when new CRS information comes available. For those portfolios, we consider a trading strategy that is long for the portfolio with the lowest transition risk exposure (Q1 portfolio) and short for the portfolios with higher transition risk exposures. If the market efficiently prices the climate transition risk, then our trading strategy should not yield abnormal returns; contrarily, if our trading strategy generates abnormally high returns, then this suggests that markets are underreacting to transition risks as measured by the CRS.

Fig. 2 depicts the cumulative monthly portfolio returns over the sample period for both the European and US markets. For the European stock market, this figure shows that cumulative returns for the portfolio with the lowest transition risk exposure (Q1 portfolio) are above the cumulative returns of the other quintile portfolios. For the US market, in contrast, cumulative returns for the Q1-Q3 portfolios display similar

[7] See footnote 4.

Table 6
Profitability of portfolios based on CRS categories.

Panel A. European firms

		Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk	Negligible — Severe	t-statistic
(t,t + 1)	ROA	9.345	6.762	5.241	3.266	1.862	7.482	23.649
	ROE	26.437	17.979	13.324	5.566	−3.469	29.906	33.778
	EBITDA/TA	44.353	41.978	32.866	33.927	24.662	19.691	11.686
	Tobin's q	3.188	1.953	1.607	1.300	1.125	2.063	18.376
(t,t + 2)	ROA	9.463	6.920	5.249	3.977	3.467	5.996	15.931
	ROE	26.310	19.280	13.265	7.454	1.890	24.420	24.790
	EBITDA/TA	46.548	36.884	32.674	35.496	35.461	11.087	5.706
	Tobin's q	3.224	1.958	1.606	1.330	1.183	2.041	15.914
(t,t + 3)	ROA	9.622	6.959	5.232	5.087	4.533	5.089	11.004
	ROE	23.221	17.404	12.522	11.120	7.284	15.936	15.061
	EBITDA/TA	43.731	36.565	31.044	21.881	36.395	7.336	3.883
	Tobin's q	3.165	1.898	1.592	1.356	1.234	1.931	13.073

Panel B. US firms

		Negligible Risk	Low Risk	Medium Risk	High Risk	Severe Risk	Negligible — Severe	t-statistic
(t,t + 1)	ROA	6.049	7.960	6.085	4.834	−0.181	6.230	32.16
	ROE	18.854	32.367	18.799	6.711	−2.408	21.262	34.95
	EBITDA/TA	12.766	13.685	11.142	10.277	6.979	5.787	12.43
	Tobin's q	3.107	2.608	1.918	1.524	1.385	1.722	15.81
(t,t + 2)	ROA	6.502	8.099	6.089	4.616	−1.883	8.386	34.37
	ROE	19.789	36.358	19.400	5.351	−6.359	26.149	34.91
	EBITDA/TA	12.810	13.953	11.049	9.983	4.705	8.105	16.48
	Tobin's q	3.071	2.642	1.927	1.530	1.395	1.676	13.78
(t,t + 3)	ROA	6.987	8.365	6.163	4.837	1.069	5.918	19.95
	ROE	21.082	38.408	20.423	5.307	−0.465	21.547	24.35
	EBITDA/TA	13.139	14.212	11.040	10.040	8.601	4.538	6.89
	Tobin's q	3.086	2.707	1.934	1.545	1.393	1.693	11.92

This table shows average profitability of portfolios comprised of firms with a CRS of 0 (negligible risk), 1 to 9.99 (low risk), 10 to 29.99 (medium risk), 30 to 49.99 (high risk) and 50 or more (severe risk). At the end of each year *t*, firms are included in one of the five portfolios according to their CRS and this portfolio holds for the 1-year, 2-year and 3-year future periods following portfolio configuration. Reported values are average profitability over the sample period from 2013 to 2018, with profitability measured by the annual return on assets (ROA), the annual return on equity (ROE), annual earnings before interest, tax, depreciation and amortization scaled by total assets (EBITDA/TA) and Tobin's q (the annual ratio between the market value of the firm over its asset replacement cost). Negligible – Severe denotes the difference in profitability for portfolios with negligible and severe transition risk exposure, with the t-statistic indicating the statistical significance of that difference.

upward trends and values, while the portfolio with the highest transition risk exposure (Q5 portfolio) displays lower cumulative returns. The graphical evidence also reflects large differences between cumulative returns between the Q1 and Q5 portfolios for both the European and US stock markets.

For each quintile portfolio we compute monthly excess returns and factor-adjusted alphas. Excess returns are computed as raw portfolio returns net of the European or US risk-free rate for the European and the US markets, respectively. Adjusted-alphas are computed using the capital asset pricing model (CAPM) model, Carhart (1997) four-factor model, Fama and French's (2015, 2017) five-factor model and the five-factor model augmented with the momentum factor, with information on factors sourced from the Fama-French data library.[8] Those estimates are reported in Table 9.

The mean excess returns for the Q1 portfolios for Europe and the USA are 0.64% and 0.77% per month, respectively, both significantly different from zero. Moreover, excess returns gradually reduce as the transition risk of the portfolio increases. In testing for differences between the Q1 and Q5 portfolios, the Newey and West (1987) t-statistic reveals that portfolios with lower transition risk exposure offer significantly higher returns than portfolios with higher exposures, at 0.51% and 0.76% per month (6.12% and 9.12% annualized) in the European and US markets, respectively. In contrast, the outcomes for the two markets are different for the alternative trading strategies, consisting of long positions for the Q1 portfolio and short positions for the Q2-Q4 portfolios. For the European market the Q1 portfolio offers significantly greater returns than the Q2-Q4 portfolios, with differences shrinking as the transition risk falls. For the US market, in contrast, longing in the Q1 portfolio and shorting in the Q2-Q4 portfolios do not generate significant extra returns, a result consistent with the above-reported evidence regarding profitability measures for the US firms.

Estimates for risk-adjusted returns reported in Table 9 show that the alpha values gradually decrease from the Q1 to the Q5 portfolio, both in the European and US markets. Alphas are statistically significant for the Q1 portfolio, while significance is mixed for the remaining quintile portfolios. Using the six-factor model, we find that long and short positions in the Q1 and Q5 portfolios yield alphas of 0.43% and 0.47% per month (5.16% and 5.54% annualized), with Newey-West t-statistics of 3.21 and 1.83 for European and US markets, respectively. Moreover, our empirical evidence shows that the trading strategy of a long position in the Q1 portfolio and a short position in the Q2-Q4 portfolios yields positive and significant risk-adjusted returns for short positions in the Q3 and Q4 portfolios for the European market, while offering no significant risk-adjusted returns for the US market.

Conducting a bivariate portfolio analysis, we further explore how quintile portfolios behave according to the market beta of the portfolio, with firms now double-sorted in ascending order according to their CRS and market beta. Table 10 reports the alphas estimated for those portfolios.

For European portfolios, the empirical results show that alphas are significant for the Q2 and Q3 portfolios of the market beta distribution and the Q1 portfolio of the CRS distribution. Consistent with the evidence reported in Table 9, alpha values decrease as we move from Q1 to Q5 of the CRS distribution and also decrease as the beta values increase.

8 https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html.

Table 7
Firm profitability and climate transition risk.

Panel A. European firms

	ROA			ROE			EBITDA/TA			Tobin's q		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
q1	0.768***	0.618***	0.578***	1.564***	1.722***	1.783***	0.620***	0.474***	0.461***	0.117***	0.037**	0.057***
	(4.76)	(3.83)	(4.48)	(3.87)	(4.83)	(4.48)	(20.23)	(2.95)	(3.72)	(35.45)	(2.12)	(3.84)
Lagged variable	0.735***	0.699***	0.656***	0.628***	0.600***	0.509***	0.821***	0.784***	0.741***	0.903***	0.879***	0.835***
	(35.32)	(34.88)	(25.25)	(16.40)	(15.55)	(11.25)	(50.40)	(46.30)	(33.18)	(28.71)	(29.75)	(27.54)
Size			−0.316***			−0.167			−0.341***			−0.055***
			(−3.14)			(−0.64)			(−3.53)			(−4.09)
D/A			0.007*			0.049**			0.018***			−0.002***
			(1.66)			(2.44)			(4.07)			(−3.13)
S/A			1.083***			4.255***			1.158***			0.005
			(4.18)			(4.68)			(3.94)			(0.32)
Dividends			1.440***			4.680***			0.650**			0.060*
			(3.70)			(6.15)			(2.13)			(1.70)
M/B			0.042***			0.249***			0.035***			0.004**
			(7.20)			(4.70)			(5.26)			(2.12)
Constant	1.539***	2.802***	4.911***	5.125***	7.623***	0.509	1.787***	2.912***	6.068***	0.145***	0.236***	1.098***
	(6.63)	(11.47)	(3.52)	(5.48)	(10.57)	(0.15)	(5.82)	(16.51)	(4.14)	(4.87)	(3.25)	(5.19)
Sector FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
R^2	0.550	0.563	0.595	0.414	0.427	0.463	0.695	0.705	0.712	0.836	0.845	0.850

Panel B. US firms

	ROA			ROE			EBITDA/TA			Tobin's q		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
q1	0.232	0.231	−0.223	0.568	0.565	−0.461	0.352	0.348	−0.113	0.068	0.067	−0.025
	(0.59)	(0.58)	(−0.87)	(0.54)	(0.53)	(−0.57)	(1.63)	(1.63)	(−0.47)	(1.14)	(1.11)	(−0.53)
Lagged variable	0.740***	0.742***	0.688***	0.786***	0.785***	0.721***	0.813***	0.815***	0.754***	0.913***	0.913***	0.890***
	(19.57)	(19.50)	(19.62)	(19.87)	(19.93)	(20.52)	(24.82)	(25.46)	(16.72)	(48.88)	(47.67)	(47.55)
Size			−0.287***			−0.458			−0.231***			−0.040**
			(−3.01)			(−1.21)			(−2.96)			(−2.03)
D/A			0.017***			0.134***			0.023***			0.002***
			(4.48)			(9.15)			(5.64)			(2.63)
S/A			0.767***			3.258***			0.684*			0.003
			(2.85)			(9.96)			(1.78)			(0.16)
Dividends			0.513**			3.741***			0.355			0.085***
			(2.08)			(6.94)			(1.00)			(2.92)
M/B			0.002			0.073*			0.000			−0.001
			(0.35)			(1.66)			(−0.01)			(−0.95)
Constant	1.741***	1.818***	5.782***	4.652***	3.591***	4.119	2.229***	2.682***	6.373***	0.171***	0.172***	0.776**
	(3.17)	(5.81)	(3.44)	(4.32)	(4.60)	(0.78)	(5.02)	(6.43)	(4.92)	(5.24)	(4.01)	(2.47)
Sector FE	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
R^2	0.551	0.560	0.582	0.587	0.588	0.614	0.671	0.677	0.689	0.835	0.837	0.840

This table shows a panel regression of firm profitability — measured by annual return on assets (ROA), annual return on equity (ROE), annual earnings before interest, tax, depreciation, and amortization scaled by total assets (EBITDA/TA) and annual ratio between the market value of the firm over its asset's replacement cost (Tobin's q) — on a dummy variable q1 that takes the value 1 if the asset is in the lower quintile of the annual distribution of CRS and 0 otherwise. Control variables include a lagged profitability measure, size, the natural logarithm of the book value of total assets, D/TA as annual total debt over total assets, S/TA as annual sales over total assets, Dividends as an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise, M/B as the annual ratio between the market price per share over the book value per share for the firm and, finally, sectoral and annual year fixed effects (FE), and country FE for the European countries. Data cover the period 2013–2018. T-statistics are reported in parentheses and computed using clustered standard errors by time and firm. The superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Comparing portfolios, risk-adjusted returns for the Q1 and Q5 portfolios are significantly different independently of the market beta of the portfolio; this result holds for different factor pricing models. Evidence is mixed, however, regarding differences in risk-adjusted returns between the Q1 portfolio and the Q4, Q3 and Q2 portfolios, which depend on the factor pricing model and the portfolio beta.

As for the US portfolios, our evidence indicates that risk-adjusted returns are negative and significant for portfolios in the Q3-Q5 portfolios of the beta distribution, and also that the risk-adjusted returns decrease and the transition risk increases. Evidence is mixed on the significance of the alphas for the Q1 and Q2 portfolios of the beta distribution. Risk-adjusted returns decrease as market beta exposure increases. In testing differences between the Q1 portfolio and the remaining portfolios, our results corroborate the evidence reported in Table 9 Panel B, as differences between risk-adjusted returns for the Q1 and Q5 quintile portfolios are significant for portfolios in the Q3-Q5 portfolios of the beta distribution. For bivariate portfolios, we also find that differences in the alphas between the Q1 and Q4 portfolios are significant for Q4 portfolios of the beta distribution.

Overall, our evidence on excess returns and risk-adjusted returns for the long-short trading strategy indicates that stocks with lower transition risk exposure offer a greater return to investors, consistent with the fact that markets underreact to climate transition risk. Arguably, in market equilibrium, stocks with lower transition risk exposure should offer lower returns than stocks with higher climate transition risk exposure. Our evidence suggests that markets overprice stocks with high

Table 8
Firm profitability and CRS category.

Panel A. European firms

	ROA			ROE			EBITDA/TA			Tobin's q		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Negligible risk	0.781***	0.663***	0.605***	1.531***	1.757***	1.781***	0.624***	0.504***	0.472***	0.119***	0.042**	0.059***
	(4.83)	(3.54)	(3.89)	(3.84)	(4.12)	(4.08)	(39.88)	(2.93)	(3.61)	(88.66)	(2.48)	(3.27)
Lagged variable	0.735***	0.699***	0.656***	0.628***	0.600***	0.509***	0.821***	0.784***	0.741***	0.902***	0.879***	0.835***
	(35.29)	(34.95)	(25.21)	(16.38)	(15.53)	(11.24)	(50.45)	(46.38)	(33.24)	(28.83)	(29.82)	(27.55)
Size			−0.315***			−0.164			−0.340***			−0.055***
			(−3.11)			(−0.63)			(−3.51)			(−4.07)
D/A			0.007*			0.049**			0.018***			−0.002***
			(1.66)			(2.44)			(4.09)			(−3.10)
S/A			1.082***			4.251***			1.157***			0.005
			(4.18)			(4.67)			(3.94)			(0.31)
Dividends			1.441***			4.678***			0.651**			0.060*
			(3.68)			(6.10)			(2.13)			(1.69)
M/B			0.042***			0.249***			0.035***			0.004**
			(7.17)			(4.69)			(5.25)			(2.12)
Constant	1.539***	1.488***	4.892***	5.135***	7.625***	0.484	1.788***	2.909***	6.056***	0.145***	0.235***	1.096***
	(6.65)	(10.76)	(3.49)	(5.52)	(10.55)	(0.14)	(5.83)	(16.10)	(4.11)	(4.89)	(3.21)	(5.18)
Sector FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Country FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
R^2	0.550	0.563	0.595	0.414	0.428	0.463	0.695	0.7056	0.712	0.836	0.845	0.850

Panel B. US firms

	ROA			ROE			EBITDA/TA			Tobin's q		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Negligible risk	0.217	0.216	−0.251	0.518	0.515	−0.531	0.346*	0.342*	−0.133	0.068	0.067	−0.025
	(0.57)	(0.57)	(−1.05)	(0.50)	(0.50)	(−0.70)	(1.75)	(1.75)	(−0.57)	(1.19)	(1.15)	(−0.57)
Lagged variable	0.740***	0.742***	0.688***	0.786***	0.785***	0.721***	0.813***	0.815***	0.754***	0.913***	0.913***	0.890***
	(19.52)	(19.45)	(19.58)	(19.87)	(19.92)	(20.52)	(24.79)	(25.43)	(16.70)	(49.30)	(48.18)	(47.70)
Size			−0.287***			−0.459			−0.231***			−0.040**
			(−3.02)			(−1.22)			(−2.98)			(−2.03)
D/A			0.017***			0.134***			0.023***			0.002***
			(4.48)			(9.15)			(5.63)			(2.63)
S/A			0.766***			3.255***			0.683*			0.003
			(2.84)			(10.12)			(1.77)			(0.16)
Dividends			0.509**			3.731***			0.352			0.085***
			(2.07)			(6.89)			(0.99)			(2.91)
M/B			0.002			0.073*			0.000			−0.001
			(0.35)			(1.66)			(0.00)			(−0.95)
Constant	1.744***	1.821***	5.803***	4.664***	3.603***	4.168	2.230***	2.681***	6.387***	0.171***	0.171***	0.777**
	(3.19)	(5.86)	(3.48)	(4.34)	(4.63)	(0.79)	(5.05)	(6.45)	(4.97)	(5.21)	(3.99)	(2.48)
Sector FE	No	No	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes
Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
R^2	0.551	0.560	0.582	0.587	0.588	0.614	0.671	0.677	0.689	0.836	0.837	0.840

This table shows a panel regression of firm profitability — measured by annual return on assets (ROA), annual return on equity (ROE), annual earnings before interest, tax, depreciation, and amortization scaled by total assets (EBITDA/TA) and annual ratio between the market value of the firm over its asset's replacement cost (Tobin's q) — on a dummy variable 'Negligible risk' that takes the value 1 if the asset has CRS = 0. Control variables include a lagged profitability measure, size, the natural logarithm of the book value of total assets, D/TA as annual total debt over total assets, S/TA as annual sales over total assets, Dividends as an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise, M/B as the annual ratio between the market price per share over the book value per share for the firm and, finally, sectoral and annual year fixed effects (FE), and country FE for the European countries. Data cover the period 2013 to 2018. T-statistics are reported in parentheses and computed using clustered standard errors by time and firm. The superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

transition risk exposure and underprice stocks with low transition risk exposure. Our findings are consistent with Hong et al. (2019), who document that food stock prices underreact to climate-related risks as measured by food stock exposure to drought risk.

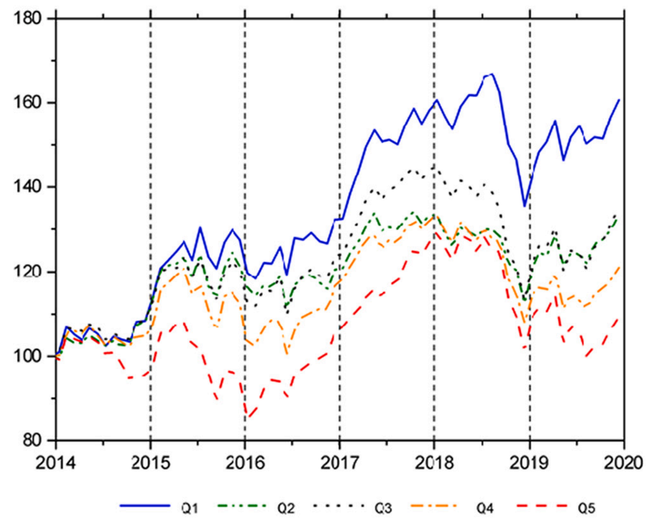
5.2. Stock return cross-section regressions

Here we explore whether the results on the impact of a climate transition risk on portfolio returns hold when we consider specific cross-section information at the stock returns level. To that end, we examine the cross-section relationship between transition risk and expected returns running Fama and MacBeth's (1973) regressions of the one-month-ahead stock returns on a dummy variable q1 equal to 1 for stocks in the Q1 portfolio and 0 otherwise, together with a set of control variables:

$$r_{i,t+1} = \mu + \beta \ q1_{i,t} + \theta \ r_{i,t} + \gamma \ X_{i,t} + \varepsilon_{i,t+1}, \tag{2}$$

where $r_{i,\ t+1}$ is the excess return of stock i in month $t+1$, and the parameters β and θ account for the effect of the climate transition risk of asset i and return persistence, respectively, on the one-month-ahead stock returns. The control variables included in X are as described in what follows.

Monthly information on firm size, defined as the natural log of market capitalization, and price-to-book ratio are considered, along with the market beta of stock i at time t as computed from the CAPM



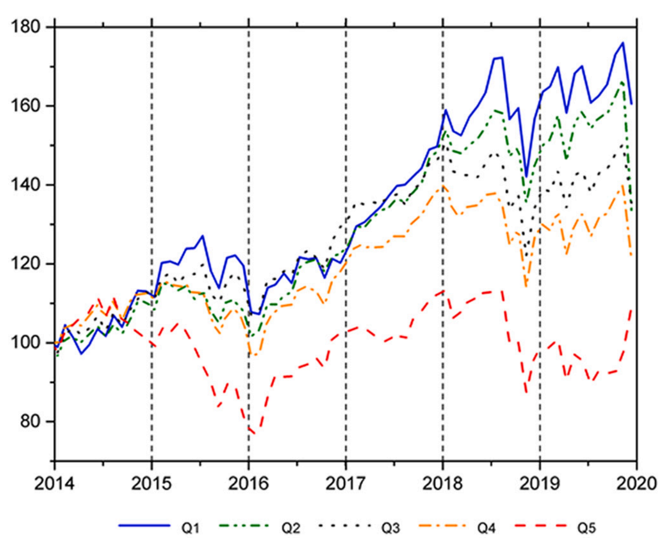


Fig. 2. Cumulative portfolio returns for quintile portfolios.
This figure depicts the cumulative monthly returns for quintile portfolios Q1 to Q5 for European (Panel A) and US (Panel B) firms, annually sorted by their climate transition risk as given by the CRS. Panel A. European firms. Panel B. US firms.

model and the co-skewness of asset i defined as (Harvey & Siddique, 2000):

$$\text{Co-Skew}_{i,t} = \frac{E(\varepsilon_{i,t}, \text{MKT}_t^2)}{\sqrt{E(\varepsilon_{i,t}^2)}E(\text{MKT}_t^2)} \tag{3}$$

where $\varepsilon_{i,\ t}$ is the residual of the CAPM model and MKT denotes excess returns for the market portfolio; both measures are estimated using monthly return observations for the previous 60 months.

We also account for the effect of volatility on returns using the implied market volatility beta, $\beta_{i,\ t}^{VIX}$, estimated from the regression (see Ang, Hodrick, Xing, & Zhang, 2006):

$$\text{r}_{i,t} = \alpha_i + \beta_{i,t}\text{MKT}_t + \beta_{i,t}^{VIX}\Delta\text{VIX}_t + \varepsilon_{i,t} \tag{4}$$

Table 9
Monthly returns for quintile portfolios sorted by CRS.

Panel A. European firms

	Excess return	α_{CAPM}	$\alpha_{4-factor}$	$\alpha_{5-factor}$	$\alpha_{6-factor}$
Q1	0.645*	0.387*	0.322*	0.342*	0.443**
	(1.83)	(1.79)	(1.68)	(1.73)	(2.14)
Q2	0.378	0.140	0.214	0.107	0.274
	(1.25)	(0.67)	(0.98)	(0.54)	(1.49)
Q3	0.409	0.134	0.199	0.073	0.235
	(1.21)	(0.53)	(0.73)	(0.26)	(0.87)
Q4	0.253	−0.033	0.164	0.067	0.230
	(0.81)	(−0.13)	(0.63)	(0.27)	(0.99)
Q5	0.128	−0.201	0.021	−0.173	0.011
	(0.44)	(−0.72)	(0.08)	(−0.60)	(0.04)
Q1-Q5	0.517**	0.587***	0.302**	0.515***	0.432***
	(2.24)	(2.68)	(2.30)	(3.76)	(3.21)
Q1-Q4	0.392**	0.419**	0.158	0.275***	0.213*
	(2.07)	(2.39)	(1.42)	(2.89)	(1.95)
Q1-Q3	0.236*	0.253*	0.123	0.269***	0.208*
	(1.74)	(1.93)	(0.91)	(2.62)	(1.67)
Q1-Q2	0.267*	0.247	0.109	0.235	0.169
	(1.95)	(1.57)	(0.63)	(1.60)	(1.09)

Panel B. US firms

	Excess return	α_{CAPM}	$\alpha_{4-factor}$	$\alpha_{5-factor}$	$\alpha_{6-factor}$
Q1	0.776*	−0.269	−0.222*	−0.208*	−0.182
	(1.78)	(−1.40)	(−1.70)	(−1.69)	(−1.59)
Q2	0.689**	−0.190*	−0.168	−0.216**	−0.201*
	(1.97)	(−1.78)	(−1.49)	(−2.04)	(−1.91)
Q3	0.559	−0.397***	−0.260*	−0.249*	−0.279**
	(1.48)	(−3.14)	(−1.90)	(−1.71)	(−2.23)
Q4	0.465	−0.538***	−0.336***	−0.377***	−0.330***
	(1.19)	(−4.51)	(−2.87)	(−3.51)	(−3.03)
Q5	0.011	−1.126***	−0.665***	−0.799***	−0.658***
	(0.14)	(−4.46)	(−3.26)	(−3.44)	(−3.14)
Q1-Q5	0.765**	0.857**	0.443*	0.591**	0.476*
	(2.13)	(2.54)	(1.82)	(2.18)	(1.83)
Q1-Q4	0.312	0.270	0.113	0.170	0.148
	(1.58)	(1.14)	(0.70)	(1.24)	(1.07)
Q1-Q3	0.218	0.129	0.038	0.041	0.097
	(1.15)	(0.57)	(0.22)	(0.32)	(0.74)
Q1-Q2	0.088	−0.078	−0.054	0.008	0.019
	(0.49)	(−0.37)	(−0.29)	(0.06)	(0.13)

This table shows monthly excess returns and risk-adjusted returns for quintile portfolios denoted, from the first to the fifth quintile as Q1 to Q5. Quintile portfolios are based on ascending sorts of firms by their CRS at the beginning of year t, reconfigured at the beginning of year $t + 1$ when new CRS information is released. Quintile portfolio monthly returns are computed as the equally-weighted average monthly returns for the firms within that quintile portfolio. Risk-adjusted returns are obtained from the estimated alphas of the CAPM model, the Carhart (1994) 5-factor model, the Fama and French (2015, 2017) 5-factor model and the 5-factor model augmented with the momentum factor. Q1-Qh, for h = 2, 3, 4, 5, denotes a portfolio that is long in Q1 assets and short in Qh assets. The Newey and West (1987) t-statistic is reported in parentheses, and the superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

where ΔVIX_t is the change in the option-derived implied volatility index on day t and $\text{r}_{i,\ t}$ is the excess returns of stock i. Data for the VIX index from the Eurostoxx-50 and the S&P 100 option-derived implied volatility indices are from Bloomberg. Monthly betas are estimated using daily observations over the previous two years. Monthly stock return volatility is obtained as the standard deviation of the daily returns within that month.

We measure monthly liquidity of stock i using Amihud's (2002) illiquidity measure defined as the average ratio between absolute daily returns and daily trading volumes within the month:

$$ILLIQ_{i,t} = \frac{1}{days_{i,t}} \sum_{d=1}^{days_{i,t}} \frac{|r_{i,t,d}|}{v_{i,t,d}} \tag{5}$$

Table 10
Monthly returns for bivariate quintile portfolios double-sorted by CRS and market beta.

Panel A. European firms

		$\beta - q1$	$\beta - q2$	$\beta - q3$	$\beta - q4$	$\beta - q5$
Q1	Excess return	0.381	0.906***	0.808**	0.543	0.590
		(1.43)	(3.00)	(2.26)	(1.19)	(0.83)
	α_{CAPM}	0.448	0.766***	0.557**	0.176	−0.013
		(1.17)	(2.79)	(2.46)	(0.62)	(−0.03)
	$\alpha_{4-factor}$	0.309	0.664**	0.490**	0.062	0.088
		(0.64)	(2.35)	(2.22)	(0.26)	(0.20)
	$\alpha_{5-factor}$	0.362	0.711***	0.474**	0.127	0.040
		(0.86)	(2.84)	(2.29)	(0.51)	(0.10)
	$\alpha_{6-factor}$	0.401	0.761***	0.621***	0.201	0.233
		(0.99)	(3.12)	(3.13)	(0.93)	(0.63)
	Excess return	0.564**	0.497**	0.629*	0.295	−0.092
Q2		(2.25)	(2.06)	(1.90)	(0.76)	(−0.03)
	α_{CAPM}	0.613**	0.364*	0.393	−0.054	−0.612
		(2.45)	(1.71)	(1.48)	(−0.18)	(−1.48)
	$\alpha_{4-factor}$	0.506**	0.345	0.456**	0.082	−0.317
		(2.20)	(1.21)	(2.08)	(0.28)	(−0.93)
	$\alpha_{5-factor}$	0.546**	0.315	0.341	−0.086	−0.577*
		(2.23)	(1.16)	(1.53)	(−0.29)	(−1.73)
	$\alpha_{6-factor}$	0.590**	0.417	0.489**	0.134	−0.258
		(2.43)	(1.58)	(2.25)	(0.49)	(−0.85)
	Excess return	0.786***	0.679**	0.605*	0.168	−0.189
Q3		(3.36)	(2.48)	(1.76)	(0.46)	(−0.14)
	α_{CAPM}	0.818***	0.524**	0.351	−0.213	−0.808*
		(3.52)	(2.00)	(1.44)	(−0.64)	(−1.75)
	$\alpha_{4-factor}$	0.617***	0.451*	0.343*	−0.088	−0.325
		(2.72)	(1.65)	(1.70)	(−0.22)	(−0.68)
	$\alpha_{5-factor}$	0.670**	0.406	0.264	−0.288	−0.681
		(2.57)	(1.49)	(1.01)	(−0.82)	(−1.57)
	$\alpha_{6-factor}$	0.634**	0.519*	0.364*	−0.103	−0.237
		(2.39)	(1.96)	(1.73)	(−0.28)	(−0.51)
	Excess return	0.564**	0.541**	0.450	0.042	−0.325
Q4		(2.38)	(2.26)	(1.34)	(0.22)	(−0.30)
	α_{CAPM}	0.573**	0.389*	0.193	−0.336	−0.973**
		(2.12)	(1.74)	(0.83)	(−1.10)	(−1.98)
	$\alpha_{4-factor}$	0.588**	0.398*	0.409	−0.067	−0.499
		(2.31)	(1.88)	(1.62)	(−0.23)	(−0.96)
	$\alpha_{5-factor}$	0.571**	0.396*	0.281	−0.237	−0.665
		(1.98)	(1.78)	(1.08)	(−0.85)	(−1.32)
	$\alpha_{6-factor}$	0.613**	0.455**	0.465*	−0.005	−0.367
		(2.49)	(2.26)	(1.84)	(−0.02)	(−0.79)
Q5	Excess return	0.602**	0.448*	0.201	0.039	−0.644
		(2.37)	(1.73)	(0.61)	(0.18)	(−0.59)
	α_{CAPM}	0.632*	0.272	−0.109	−0.412	−1.379***
		(1.93)	(1.04)	(−0.40)	(−1.32)	(−2.70)
	$\alpha_{4-factor}$	0.544*	0.318	0.121	−0.036	−0.837*
		(1.92)	(1.14)	(0.43)	(−0.12)	(−1.89)
	$\alpha_{5-factor}$	0.542*	0.176	−0.090	−0.359	−1.126**
		(1.83)	(0.61)	(−0.28)	(−1.06)	(−2.47)
	$\alpha_{6-factor}$	0.499**	0.250	0.098	−0.010	−0.777*
		(1.96)	(0.94)	(0.33)	(−0.03)	(−1.83)
	Excess return	−0.221	0.458*	0.607**	0.504*	1.234***
Q1-Q5		(−0.82)	(1.92)	(2.08)	(1.67)	(2.87)
	α_{CAPM}	−0.184	0.494**	0.666**	0.588**	1.366***
		(−0.64)	(2.21)	(2.19)	(1.97)	(3.65)
	$\alpha_{4-factor}$	−0.234	0.347	0.369**	0.097	0.925***
		(−0.80)	(1.51)	(2.19)	(0.54)	(4.02)
	$\alpha_{5-factor}$	−0.180	0.536**	0.564***	0.486***	1.166***
		(−0.63)	(2.55)	(3.08)	(2.60)	(4.40)
	$\alpha_{6-factor}$	−0.098	0.511**	0.523***	0.212	1.011***
		(−0.36)	(2.36)	(2.76)	(1.23)	(3.61)
	Excess return	−0.183	0.366	0.358	0.501**	0.915***
Q1-Q4		(−0.67)	(1.58)	(1.54)	(1.99)	(2.71)
	α_{CAPM}	−0.125	0.378**	0.364	0.512**	0.961***
		(−0.44)	(2.03)	(1.48)	(2.27)	(3.00)
	$\alpha_{4-factor}$	−0.279	0.266*	0.081	0.129	0.587**
		(−0.94)	(1.87)	(0.44)	(0.80)	(2.10)
	$\alpha_{5-factor}$	−0.209	0.316**	0.193	0.364**	0.704***
		(−0.80)	(2.53)	(1.05)	(2.57)	(2.76)
	$\alpha_{6-factor}$	−0.211	0.306**	0.156	0.206	0.601**
		(−0.78)	(2.29)	(0.81)	(1.42)	(2.15)
	Excess return	−0.405*	0.227	0.203	0.375	0.779**
Q1-Q3		(−1.81)	(0.99)	(1.00)	(1.53)	(2.47)
	α_{CAPM}	−0.370	0.242	0.206	0.389*	0.796***

(continued on next page)

Table 10 (*continued*)

Panel A. European firms

		$\beta - q1$	$\beta - q2$	$\beta - q3$	$\beta - q4$	$\beta - q5$
		(−1.35)	(1.13)	(1.04)	(1.76)	(2.75)
	$\alpha_{4-factor}$	−0.346	0.286	0.127	0.308*	0.646**
		(−1.14)	(1.30)	(0.66)	(1.80)	(2.33)
	$\alpha_{5-factor}$	−0.308	0.214	0.147	0.150	0.413
		(−0.89)	(0.85)	(0.79)	(0.72)	(1.28)
	$\alpha_{6-factor}$	−0.308	0.305	0.211	0.415**	0.720***
		(−1.07)	(1.33)	(1.05)	(2.36)	(2.94)
	Excess return	−0.233	0.242	0.257	0.305	0.470*
		(−0.70)	(0.90)	(1.30)	(1.49)	(1.71)
	Excess return	−0.184	0.409**	0.179	0.249	0.682**
Q1-Q2		(−0.75)	(2.10)	(0.90)	(1.30)	(2.23)
	α_{CAPM}	−0.165	0.402**	0.164	0.230	0.599*
		(−0.60)	(2.05)	(0.80)	(1.31)	(1.90)
	$\alpha_{4-factor}$	−0.196	0.319	0.034	−0.020	0.405
		(−0.63)	(1.54)	(0.14)	(−0.15)	(1.18)
	$\alpha_{5-factor}$	−0.184	0.397**	0.134	0.213	0.616**
		(−0.68)	(1.99)	(0.68)	(1.50)	(2.02)
	$\alpha_{6-factor}$	−0.189	0.344	0.132	0.067	0.492
		(−0.63)	(1.64)	(0.58)	(0.49)	(1.52)

Panel B. US firms

		$\beta - q1$	$\beta - q2$	$\beta - q3$	$\beta - q4$	$\beta - q5$
Q1	Excess return	0.812***	1.099***	0.829**	0.937*	0.395
		(2.88)	(3.35)	(2.00)	(1.69)	(0.47)
	α_{CAPM}	0.593	0.358**	−0.156	−0.392	−1.747***
		(1.61)	(1.98)	(−0.74)	(−1.36)	(−3.54)
	$\alpha_{4-factor}$	0.547*	0.275*	−0.190	−0.305	−1.488***
		(1.72)	(1.77)	(−1.30)	(−1.44)	(−3.50)
	$\alpha_{5-factor}$	0.531*	0.249*	−0.177	−0.302	−1.420***
		(1.72)	(1.71)	(−1.15)	(−1.50)	(−3.50)
	$\alpha_{6-factor}$	0.572*	0.274*	−0.178	−0.286	−1.427***
		(1.81)	(1.69)	(−1.34)	(−1.52)	(−3.79)
	Excess return	0.817***	0.577**	0.803**	0.774	0.569
Q2		(3.21)	(2.19)	(2.14)	(1.59)	(0.79)
	α_{CAPM}	0.751**	−0.010	−0.070	−0.408**	−1.223***
		(2.22)	(−0.06)	(−0.35)	(−2.12)	(−3.79)
	$\alpha_{4-factor}$	0.562**	−0.072	−0.021	−0.362**	−1.071***
		(1.97)	(−0.51)	(−0.09)	(−2.26)	(−3.40)
	$\alpha_{5-factor}$	0.535*	−0.087	0.016	−0.302**	−1.010***
		(1.95)	(−0.64)	(0.07)	(−2.36)	(−3.34)
	$\alpha_{6-factor}$	0.524**	−0.105	−0.054	−0.366**	−1.087***
		(2.03)	(−0.79)	(−0.29)	(−2.37)	(−3.42)
	Excess return	0.619**	0.803**	0.566	0.573	0.305
Q3		(2.56)	(2.55)	(1.48)	(1.13)	(0.43)
	α_{CAPM}	0.493	0.179	−0.354**	−0.707***	−1.601***
		(1.60)	(0.71)	(−1.97)	(−3.90)	(−4.72)
	$\alpha_{4-factor}$	0.440	0.259	−0.199	−0.493***	−1.191***
		(1.42)	(0.98)	(−1.20)	(−2.96)	(−3.98)
	$\alpha_{5-factor}$	0.390	0.185	−0.264	−0.474***	−1.147***
		(1.23)	(0.67)	(−1.58)	(−3.12)	(−3.77)
	$\alpha_{6-factor}$	0.398	0.231	−0.207	−0.508***	−1.161***
		(1.58)	(0.98)	(−1.30)	(−2.94)	(−4.38)
	Excess return	0.809***	0.749**	0.506	0.155	0.175
Q4		(2.75)	(2.32)	(1.26)	(0.36)	(0.27)
	α_{CAPM}	0.740***	0.127	−0.508***	−1.234***	−1.829***
		(2.84)	(0.55)	(−3.36)	(−6.56)	(−4.93)
	$\alpha_{4-factor}$	0.649**	0.132	−0.334**	−0.928***	−1.421***
		(2.48)	(0.55)	(−2.10)	(−6.58)	(−4.74)
	$\alpha_{5-factor}$	0.621**	0.156	−0.304**	−0.860***	−1.306***
		(2.22)	(0.67)	(−2.10)	(−5.47)	(−4.41)
	$\alpha_{6-factor}$	0.630***	0.105	−0.327**	−0.933***	−1.376***
		(2.88)	(0.46)	(−2.28)	(−6.77)	(−5.29)
Q5	Excess return	0.289	0.388	0.117	0.012	−0.807
		(1.16)	(1.21)	(0.34)	(0.11)	(−0.63)
	α_{CAPM}	0.250	−0.305	−0.981***	−1.478***	−3.127***
		(0.70)	(−1.27)	(−3.20)	(−5.29)	(−5.10)
	$\alpha_{4-factor}$	0.205	−0.074	−0.733***	−1.049***	−2.338***
		(0.56)	(−0.40)	(−2.73)	(−6.21)	(−4.55)
	$\alpha_{5-factor}$	0.283	−0.009	−0.638***	−0.889***	−2.086***
		(0.82)	(−0.04)	(−2.63)	(−5.23)	(−4.32)
	$\alpha_{6-factor}$	0.153	−0.076	−0.735***	−1.052***	−2.296***

(*continued on next page*)

Table 10 (*continued*)

Panel B. US firms

		$\beta - q1$	$\beta - q2$	$\beta - q3$	$\beta - q4$	$\beta - q5$
		(0.51)	(−0.40)	(−2.96)	(−5.89)	(−4.42)
	Excess return	0.523	0.711**	0.712*	0.926**	1.201*
Q1-Q5		(1.27)	(2.20)	(1.87)	(2.27)	(1.71)
	α_{CAPM}	0.344	0.662**	0.825**	1.086***	1.379**
		(0.74)	(2.07)	(2.30)	(2.85)	(2.14)
	$\alpha_{4-factor}$	0.343	0.348	0.543*	0.745***	0.851
		(0.79)	(1.62)	(1.66)	(2.67)	(1.53)
	$\alpha_{5-factor}$	0.248	0.258	0.461	0.588**	0.666
		(0.61)	(1.16)	(1.46)	(2.12)	(1.43)
	$\alpha_{6-factor}$	0.419	0.350	0.557*	0.765***	0.869*
		(1.06)	(1.61)	(1.69)	(2.77)	(1.65)
	Excess return	0.003	0.351	0.324	0.782***	0.220
Q1-Q4		(0.01)	(1.39)	(1.31)	(2.89)	(0.61)
	α_{CAPM}	−0.146	0.231	0.352	0.842***	0.081
		(−0.43)	(0.90)	(1.28)	(3.33)	(0.22)
	$\alpha_{4-factor}$	−0.101	0.142	0.144	0.623***	−0.067
		(−0.31)	(0.50)	(0.65)	(3.44)	(−0.23)
	$\alpha_{5-factor}$	−0.091	0.093	0.127	0.558***	−0.114
		(−0.28)	(0.35)	(0.56)	(2.99)	(−0.43)
	$\alpha_{6-factor}$	−0.058	0.169	0.149	0.646***	−0.051
		(−0.19)	(0.68)	(0.71)	(3.72)	(−0.19)
	Excess return	0.193	0.296	0.263	0.364	0.090
Q1-Q3		(0.71)	(1.36)	(1.02)	(1.61)	(0.24)
	α_{CAPM}	0.101	0.178	0.198	0.315	−0.147
		(0.35)	(0.70)	(0.73)	(1.35)	(−0.38)
	$\alpha_{4-factor}$	0.108	0.016	0.009	0.188	−0.297
		(0.41)	(0.06)	(0.04)	(1.18)	(−1.09)
	$\alpha_{5-factor}$	0.141	0.064	0.086	0.172	−0.273
		(0.52)	(0.22)	(0.36)	(1.00)	(−1.11)
	$\alpha_{6-factor}$	0.174	0.043	0.028	0.222	−0.266
		(0.75)	(0.19)	(0.14)	(1.29)	(−1.02)
	Excess return	0.251	0.116	0.129	0.221	−0.233
		(1.05)	(0.48)	(0.53)	(1.37)	(−1.01)
	Excess return	−0.005	0.522***	0.026	0.164	−0.174
Q1-Q2		(−0.02)	(2.72)	(0.12)	(0.74)	(−0.47)
	α_{CAPM}	−0.158	0.367	−0.087	0.015	−0.525
		(−0.59)	(1.43)	(−0.32)	(0.08)	(−1.45)
	$\alpha_{4-factor}$	−0.014	0.347	−0.170	0.057	−0.417
		(−0.04)	(1.54)	(−0.68)	(0.28)	(−1.28)
	$\alpha_{5-factor}$	−0.004	0.336	−0.193	0.000	−0.410
		(−0.01)	(1.61)	(−0.69)	(0.00)	(−1.30)
	$\alpha_{6-factor}$	0.049	0.379*	−0.124	0.079	−0.340
		(0.15)	(1.87)	(−0.51)	(0.42)	(−1.10)

This table shows monthly excess returns and risk-adjusted returns for quintile portfolios based on an ascending sort of firms by their CRS (denoted by Q1, Q2, Q3, Q4 and Q5) and market beta (denoted by β − q1, β − q2, β − q3, β − q4, β − q5) at the beginning of year *t*, reconfigured at the beginning of year *t* + *1* when new CRS information and market beta is available. Quintile portfolio monthly returns are computed as the equally-weighted average monthly returns for the firms within that quintile portfolio. Risk-adjusted returns are obtained from the estimated alphas of the CAPM model, the Carhart (1994) 5-factor model, the Fama and French (2015, 2017) 5-factor model and the 5-factor model augmented with the momentum factor. Q1-Qh, for h = 2, 3, 4, 5, denotes a portfolio that is long in Q1 assets and short in Qh assets. The Newey and West (1987) t-statistic is reported in parentheses, and the superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

where $r_{i,\ t,\ d}$ and $v_{i,\ t,\ d}$ denote, respectively, the return and volume of stock *i* on day *d* and month *t*, and $days_{i,\ t}$ is the number of trading days in month *t*. We compute the illiquidity measure for a minimum of 15 trading days with returns and non-zero trading volumes, scaling the illiquidity ratio by 10^6.

We estimate Eq. (2) for an unbalanced panel for European and US stock markets. Table 11 reports the time-series averages of the slope coefficients for the explanatory variables and the t-statistics considering different sets of control variables. The estimated coefficient for the dummy variable q1 is around 0.35 for Europe and between 0.34 and 0.39 for the USA, and is significant at the 5% and 10% levels, respectively, for all regression specifications. These estimates mean that stocks with the lowest transition risk exposure (those included in the Q1 portfolio) offer additional next-month returns with respect to stock with higher transition risk exposure, with a size for this premium amounting to an annualized 4.2% and 4.4% in the European and US markets, respectively.

Different regression specifications in Table 11 show that the inclusion of controls has negligible effects on the significance and size of the dummy variable. For control variables, we find that lagged returns have no significant impact on future monthly returns and that size predicts next-month stock returns in Europe, consistent with the evidence reported in the literature (e.g., Fama & French, 2012). We also find that the remaining control variables have no significant impact on future stock returns. Overall, this cross-section evidence, consistent with the evidence from the portfolio sort analysis, points to the fact that reducing transition risk exposure has favourable effects on stock returns at both the portfolio and firm levels. This evidence is consistent with the asset pricing theory in which uncertainty on climate change comes from the path of the economy, leading to a positive risk premium for risk-mitigating investments (Giglio et al., 2021; Lemoine, 2020).

6. Has COP21 altered CRS impact on firm profitability and stock returns?

Evidence from the previous two sections indicates that, over the

Table 11
Fama-MacBeth cross-section regressions for monthly stock returns.

	European firms					US firms				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Constant	0.363	0.345	0.956	1.524***	1.513***	0.517	0.401	0.696	0.999*	0.992*
	(0.93)	(0.91)	(1.47)	(2.67)	(2.66)	(1.18)	(0.96)	(1.30)	(1.87)	(1.85)
q1	0.355**	0.355**	0.324**	0.346**	0.344**	0.360*	0.366*	0.390**	0.348*	0.349*
	(2.43)	(2.50)	(2.33)	(2.46)	(2.45)	(1.77)	(1.87)	(1.96)	(1.77)	(1.77)
Lagged return		−0.001	−0.010	−0.014	−0.014		−0.013	−0.017	−0.023	−0.023
		(−0.81)	(−0.85)	(−1.26)	(−1.25)		(−0.72)	(−1.01)	(−1.39)	(−1.39)
Market beta			−0.090	−0.016	−0.022			−0.178	−0.162	−0.162
			(−0.36)	(−0.07)	(−0.10)			(−0.60)	(−0.61)	(−0.61)
Size			−0.064	−0.103**	−0.102**			−0.012	−0.008	−0.008
			(−1.18)	(−2.11)	(−2.10)			(−0.31)	(−0.22)	(−0.21)
M/B			0.000	0.000	0.000			−0.001	−0.001	−0.001
			(−0.11)	(−0.02)	(−0.02)			(−1.11)	(−1.21)	(−1.21)
Co-skewness				0.011	0.010				0.020	0.019
				(0.15)	(0.15)				(0.24)	(0.23)
Beta-VIX				−0.169	−0.165				0.005	0.005
				(−0.94)	(−0.92)				(0.03)	(0.03)
Volatility				−0.181	−0.176				−0.225	−0.224
				(−1.58)	(−1.52)				(−1.37)	(−1.36)
Illiquidity					0.014					0.006
					(1.25)					(0.73)
#obs.	63,645	63,645	61,039	61,039	60,897	56,566	56,566	53,466	52,666	52,666
R^2	0.004	0.014	0.040	0.058	0.058	0.011	0.035	0.069	0.099	0.101

This table shows the Fama-MacBeth regressions of the one-month-ahead stock returns (in percentages) on a dummy variable q1 along with control variables for European and US stock markets. q1 is a dummy variable that takes 1 for stocks in the first quintile of the CRS distribution and 0 otherwise. Control variables include one-month-lagged stock returns, market beta of the stock computed from the CAPM model, size measured as the natural log of market value, the price-to-book ratio (M/B), co-skewness, the implied market volatility beta (Beta-VIX), return volatility measured as the standard deviation of daily stock returns within the corresponding month, and liquidity as given by Amihud (2002). The sample is unbalanced and includes monthly information from January 2013 to December 2019. T-statistics are reported in parentheses, and the superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

sample period, firms in Q1 of the CRS distribution exhibit superior profitability and stock return performance than firms in Q5, for both European and US markets. However, those differences may have changed as a result of COP21 – signed by a wide set of countries in December 2015 – that strengthens the pledge to deal with the impact of climate change. Here we examine whether COP21 has had an impact on investor's climate awareness, reflected in differences in profitability and stock return performance between firms in Q1 and Q5, as reported above for the whole sample period.

Taking the Q1 and Q5 firms in the periods before and after COP21, we conduct a DiD regression analysis for profitability and stock returns:

$$P_{i,t+1} = \mu + \beta \ q1_{i,t} + \theta \ COP21_t + \lambda \ \left(q1_{i,t} \cdot COP21_t\right) + \gamma \ Controls_{i,t} + \varepsilon_{i,t+1} \quad (6)$$

where the dependent variable $P_{i,\,t+1}$ denotes a profitability or stock return measure for firm i at time $t+1$, $q1_{i,\,t}$ is an indicator function that takes the values 1 or 0 when firm i is included in Q1 or Q5 of the CRS distribution at time t, respectively, and COP21 is a dummy variable that takes the value 1 for time periods after COP21 (2016 onwards), and 0 otherwise. Thus, the parameters β and $\beta+\lambda$ account for differences in the dependent variable between firms in Q1 and Q5 in the pre- and post-COP21 periods, respectively. Likewise, θ and $\theta+\lambda$ capture differences in the dependent variable between post- and pre-COP21 periods for firms in Q5 and Q1 (high and low transition risk, respectively). λ is the DiD parameter reporting information on how COP21 impacts on the relative profitability or stock return performance of firms with low and high transition risk exposures, with a negative (positive) value indicating that differences in performance decrease (increase) after COP21. The DiD estimator in Eq. (6) relies on the parallel trend assumption (see, e.g., Blundell & Dias, 2009).[9] For different measures of profitability or stock returns, we run the DiD regression in Eq. (6) considering the same set of control variables as in Eqs. (1) and (2).

Looking at Table 12, Panel A shows results for European firms for the DiD analysis using different profitability measures. Empirical estimates indicate that differences in profitability between firms in Q1 and Q5 of the CRS distribution, as reported in Table 7, significantly shrink in the period after COP21: the DiD parameter for all profitability measures (with the exception of Tobin's q) is negative and significant at the 1% or the 10% levels, clustering standard errors by firm and time. Our parameter estimates also indicate that firms with high exposure to climate-related risk experience notable improvements in profitability after COP21, whereas the profitability of firms with low transition risk exposure remains stable and is only marginally impacted. For European firms, this evidence is consistent with the idea that COP21 has larger positive impacts on firms less prepared for transition to a low-carbon economy.

Regarding US firms, the evidence in Table 12 Panel B indicates mixed effects of COP21 on profitability. DiD parameter estimates indicate a reduction, after COP21, in the gap between Q1 and Q5 firms for the CRS distribution for the ROA and EBITDA profitability measures, but no impact for ROE and Tobin's q ratio. Likewise, parameter estimates reveal that US firms' profitability improves after COP21 for Q1 and Q5 firms, with especially large improvements for firms in Q5.

Overall, our evidence from the DiD analysis for profitability indicates that COP21 has had a positive impact in improving the performance of firms with high transition risk exposure and reducing their worser performance, even though this effect is dissimilar in size for European and US firms.

Table 13 Panel A shows results for the DiD analyses of stock returns for European and US firms. For European firms, empirical estimates indicate that differences shrunk between stock returns for firms in Q1 and Q5 of the CRS distribution, indicating a raising of awareness resulting from COP21 and a revision of climate-related risk assessments, in such a way that assets very exposed to risk are devalued relative to less exposed assets. Our results also indicate that, after COP21, stocks with high transition risk exposure offer greater returns than stocks with low transition risk exposure; this is consistent with a decrease in stock

[9] This hypothesis implies that the control and treatment group outcome variables follow parallel paths over the period prior to the date of treatment.

Table 12
Difference-in-differences estimates of the impact of COP21 on the profitability of firms in the fifth and first quintiles of the CRS distribution.

Panel A. European firms

	ROA		ROE		EBITDA/TA		Tobin's q	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Constant	6.486***	2.221	14.138***	−8.142	11.653***	3.408**	2.023***	1.182***
	(6.35)	(1.40)	(9.17)	(−1.55)	(8.59)	(2.30)	(10.21)	(5.93)
q1	3.995***	1.090**	9.291***	3.296**	5.948***	1.378***	0.660***	0.075
	(3.91)	(2.37)	(3.45)	(2.12)	(4.86)	(3.51)	(3.50)	(1.14)
COP21	2.212***	1.281***	6.909***	3.195***	3.077***	1.921***	0.187**	−0.143**
	(4.23)	(5.61)	(8.74)	(4.39)	(6.23)	(6.84)	(2.09)	(2.49)
q1 x COP21	−1.920**	−1.253**	−5.841***	−3.414*	−2.987***	−1.645***	−0.118**	−0.002
	(−5.26)	(−1.99)	(−3.17)	(−1.87)	(−2.96)	(−3.30)	(−2.03)	(−0.02)
Lagged variable		0.648***		0.521***		0.711***		0.826***
		(14.86)		(7.11)		(24.59)		(13.89)
Size		−0.281**		0.163		−0.299***		−0.062***
		(−2.30)		(0.44)		(−2.92)		(−5.57)
D/A		0.025***		0.075**		0.035***		−0.003***
		(2.83)		(2.28)		(4.07)		(−4.71)
S/A		1.802***		5.206***		1.899***		0.031
		(7.19)		(5.91)		(4.50)		(0.72)
Dividends		1.531***		4.641***		0.725		−0.012
		(2.90)		(6.46)		(1.34)		(−0.48)
M/B		0.044**		0.207***		0.045***		0.005*
		(2.54)		(8.78)		(3.80)		(1.73)
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.170	0.615	0.129	0.492	0.185	0.689	0.303	0.853

Panel B. US firms

	ROA		ROE		EBITDA/TA		Tobin's q	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Constant	8.341***	3.53	19.649***	−7.544	13.529***	2.413	1.864***	0.826**
	(8.08)	(1.49)	(6.86)	(−1.27)	(9.73)	(1.15)	(12.39)	(2.08)
q1	1.776*	0.995	8.969**	3.341***	2.163	1.242***	0.608***	0.001
	(1.81)	(1.62)	(2.50)	(2.67)	(1.56)	(6.40)	(3.01)	(0.01)
COP21	1.708***	2.418***	5.468**	6.075***	3.340***	4.374***	−0.022	−0.127*
	(6.76)	(3.30)	(2.56)	(2.99)	(8.64)	(7.41)	(−0.37)	(−1.72)
q1 x COP21	−2.005**	−2.459*	−3.226	−4.815	−1.771*	−2.821***	0.023	0.165
	(−2.53)	(−1.75)	(−1.56)	(−1.27)	(−1.93)	(−2.61)	(1.17)	(1.27)
Lagged variable		0.681***		0.653***		0.731***		0.856***
		(18.06)		(15.66)		(13.24)		(28.55)
Size		−0.195		0.273		−0.192		−0.043*
		(−1.24)		(0.64)		(−1.20)		(−1.70)
D/A		0.021***		0.095***		0.023***		0.001
		(3.28)		(6.05)		(3.57)		(0.56)
S/A		1.077**		3.472***		1.046		0.001
		(2.01)		(3.52)		(1.51)		(0.03)
Dividends		0.524		3.606***		0.424		0.072
		(1.56)		(4.60)		(1.07)		(1.46)
M/B		−0.001		0.068		−0.004		−0.001
		(−0.19)		(1.05)		(−0.69)		(−1.06)
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.122	0.573	0.092	0.556	0.108	0.627	0.263	0.834

This table shows estimation results for the difference-in-differences regression in Eq. (6) for profitability measures, firm's profitability — measured by annual return on assets (ROA), annual return on equity (ROE), annual earnings before interest, tax, depreciation, and amortization scaled by total assets (EBITDA/TA) and annual ratio between the market value of the firm over its asset's replacement cost (Tobin's q) — on a dummy variable q1 that takes the value 1 if the asset is in the first quintile of the annual CRS distribution and 0 if the asset is in the fifth quintile of the CRS distribution, on a dummy variable COP21 that takes the value 1 for time periods after the Paris Climate Agreement (2016 onwards) and 0 otherwise, and the interaction between these two dummies. Control variables include a lagged profitability measure, size, the natural logarithm of the book value of total assets, D/TA as annual total debt over total assets, S/TA as annual sales over total assets, Dividends as an indicator variable that takes the value 1 if the firm pays dividends and 0 otherwise, M/B as the annual ratio between book value of equity and the market value of equity for the firm, and, finally, sectoral and year fixed effects (FE), and country FE for the European countries. Data cover the period 2013 to 2018. T-statistics are reported in parentheses and computed using clustered standard errors by time and firm. The superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

prices for the former and an increase for the latter. However, the size of the price correction according to the climate transition risk is low, with an annual value of below 1%.

As for US firms, results in Table 13 Panel B indicate that COP21 had no impact on the return spread between firms with low and high transition risk exposures: firms with little exposure remain undervalued or offer higher returns with respect to very exposed firms. This result is consistent with the fact that investors in US markets are less climate-

Table 13
Difference-in-differences estimates of the impact of COP21 on the stock returns of firms in the fifth and first quintiles of the CRS distribution.

	European firms					US firms				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
Constant	−0.502	−0.519	0.307	0.029	0.036	0.205	0.211	0.831	−1.224	−1.236
	(−0.62)	(−0.65)	(0.29)	(0.03)	(0.03)	(0.22)	(0.24)	(0.77)	(−0.91)	(−0.92)
q1	1.165**	1.189***	1.243***	1.235***	1.231***	0.631	0.679	0.813	0.691	0.700
	(2.93)	(3.00)	(2.89)	(2.86)	(2.86)	(1.06)	(1.12)	(1.33)	(1.16)	(1.17)
COP21	1.547	1.575	1.566	1.542	0.740	0.507	0.581	0.571	3.164**	3.165**
	(1.50)	(1.53)	(1.49)	(1.47)	(0.66)	(0.31)	(0.36)	(0.36)	(2.27)	(2.27)
q1 x COP21	−1.279***	−1.306***	−1.368***	−1.354***	−1.344***	−0.884	−0.951	−0.931	−0.815	−0.815
	(−2.77)	(−2.84)	(−2.79)	(−2.77)	(−2.76)	(−1.08)	(−1.15)	(−1.14)	(−1.01)	(−1.01)
Lagged return		−0.024	−0.024	−0.023	−0.022		−0.060	−0.066*	−0.067*	−0.067*
		(−1.17)	(−1.17)	(−1.14)	(−1.12)		(−1.58)	(−1.69)	(−1.77)	(−1.77)
Market beta			0.197	0.172	0.166			0.109	0.031	0.031
			(0.88)	(0.85)	(0.81)			(0.55)	(0.15)	(0.16)
Size			−0.106*	−0.089	−0.088			−0.087	−0.064	0.064
			(−1.67)	(−1.44)	(−1.43)			(−1.59)	(−1.37)	(−1.37)
M/B			0.000	0.000	0.000			−0.000**	−0.000*	−0.000*
			(0.36)	(0.28)	(0.27)			(−1.92)	(−1.91)	(−1.93)
Co-skewness				0.057	0.053				0.037	0.037
				(0.61)	(0.57)				(0.27)	(0.27)
Beta-VIX				0.126	0.131				0.217	0.217
				(0.63)	(0.66)				(0.96)	(0.96)
Volatility				0.104	0.111				0.160	0.160
				(0.61)	(0.65)				(0.50)	(0.49)
Illiquidity					−0.016					0.001
					(−1.15)					(0.01)
#obs.	25,507	25,507	24,396	24,396	24,337	25,416	25,097	23,753	23,399	23,399
R^2	0.013	0.014	0.014	0.015	0.015	0.019	0.023	0.024	0.026	0.026

This table shows estimation results for the difference-in-differences regression in Eq. (6) for firm's monthly returns on a dummy variable q1 that takes the value 1 if the asset is in the first quintile of the annual CRS distribution and 0 if the asset is in the fifth quintile of the CRS distribution, on a dummy variable COP21 that takes the value 1 for time periods after the Paris Climate Agreement (2016 onwards) and 0 otherwise, and the interaction between these two dummies. Control variables include one-month-lagged stock return, market beta of the stock computed from the CAPM model, size measured as the natural log of market value, the price-to-book ratio (M/B), co-skewness, the implied market volatility beta (Beta-VIX), return volatility measured as the standard deviation of daily stock returns within the corresponding month, liquidity as given by Amihud (2002) and, finally, sectoral and year fixed effects (FE), and country FE for the European countries. The sample is unbalanced and includes monthly information from January 2013 to December 2019. T-statistics are reported in parentheses and computed using clustered standard errors by time and firm. The superscripts ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

aware than investors in the European market. Finally, for the control variables, our evidence indicates that while many control variables are not significant, size has negative and significant effects on stock returns in both markets, while price-to-book ratio is only significant for the US market.

Overall, our empirical evidence on the effects of COP21 on the relative values of firms with low and high transition risk exposure is consistent with the fact that investors in Europe correct firm values according to the vulnerability of the firm to climate transition risk, whereas investors in the USA are insensitive to this risk: firms with low transition risk exposure offer an additional return over firms with high transition risk exposure. For the periods before and after COP21, this result is graphically illustrated in Fig. 3, which reflects the cumulative returns of the quintile portfolios represented in Fig. 2.

7. Robustness analysis

In this section, we examine whether previous evidence is consistent with proxies to transition risks that differ from the CRS information used in the above analyses. Specifically, we focus on GGP Scopes 1, 2 and 3 carbon emissions, which reflect different firm level exposures to emissions and indirect information on transition risk. Using GGP Scope information instead of CRS information, in the online appendix we provide similar evidence as reported above. Descriptive statistics show that CRS and GGP Scope carbon emissions contain different information, as some sectors have low emission levels but high CRS ratings (e.g., the financial and real estate sectors). Therefore, CRS and GGP Scope information could lead to different conclusions. However, portfolio sort analyses and carbon regressions point to similar conclusions as reported here for the CRS: firms with lower exposure to transition risk exposure as measured by GGP Scope carbon emissions exhibit better financial performance, both in the European and US markets, and also offer greater returns to investors.

We further examine whether a classification based on the ESG score has any effect on our evidence for CRS information. Classifying firms according to the "E" rating and running the same analysis as above, the empirical results also confirm the qualitative evidence obtained for the CRS.

8. Conclusions

The adverse effects of climate change urge a transition to a low-carbon economy. This transition, which entails policy and legal regulations to limit emissions, changes in technologies and modifications in consumer preferences, implies risk for the profits and values of firms.

We consider whether the transition risks to a low-carbon economy are reflected in financial performance and cross-section pricing for publicly-traded European and US firms. The transition risks are quantified at the firm level using the Sustainalytics CRS metric. The CRS, in rating the impact of transition on firm values, reports useful information to investors in terms of recognition of the potential cost of the carbon externality for investment decisions. The empirical analysis, based on univariate portfolio and cross-section regression analyses, focuses on spreads in future profitability and stock return performance between firms in the lowest and highest quintiles of the CRS distribution.

The empirical evidence for the period 2013–2018 indicates that firms with lower compared to greater exposure to climate transition risks perform better in terms of ROA, ROE, EBITDA and Tobin's q ratio. For European firms, performance gradually deteriorates as the transition risk grows, while for US firm, performances remains similar across

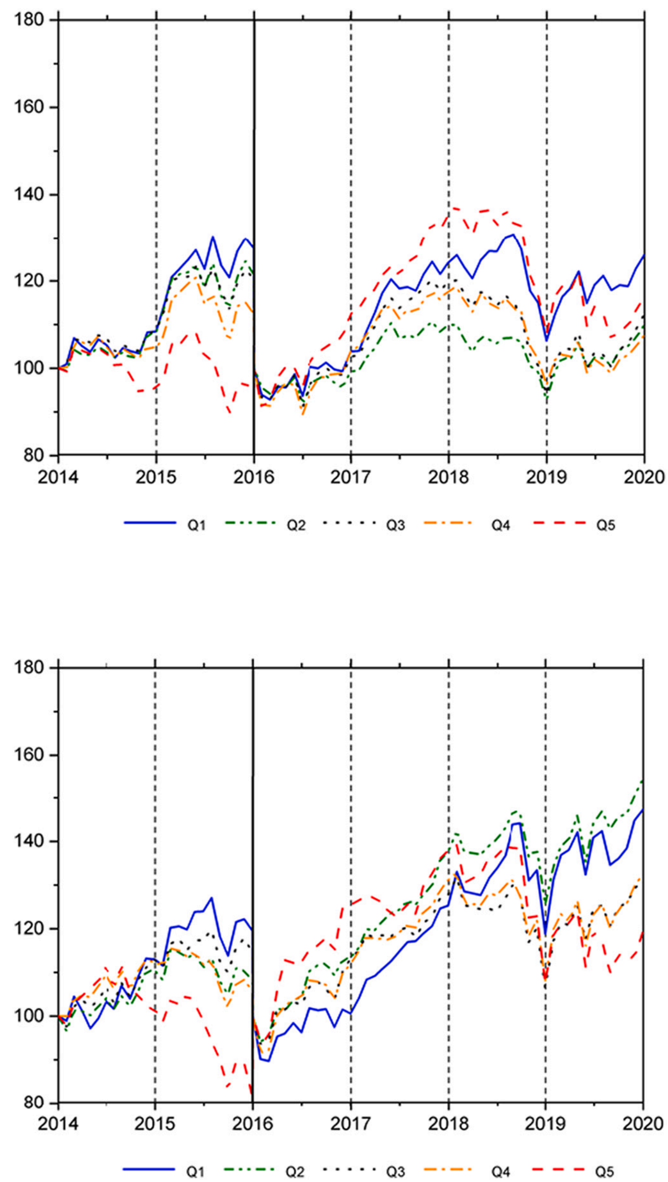


Fig. 3. Cumulative portfolio returns for quintile portfolios before and after COP21.
This figure depicts the cumulative monthly returns for quintile portfolios Q1 to Q5 for European (Panel A) and US (Panel B) firms, annually sorted by their climate transition risk as given by the CRS in the periods before and after COP21 (indicated by a bold vertical line). Panel A. European firms. Panel B. US firms.

quintiles except in the highest quintile, where firms experience significantly deteriorated performance. These results show that European firms are more sensitive to climate transition risk than US firms.

Our findings on pricing suggest that markets misprice the climate transition risk. The excess and risk-adjusted returns for a long-short trading strategy in the lowest and highest risk quintile portfolios indicate that lower-risk stocks offer greater returns to investors, which suggests that markets overprice (underprice) stocks with high (low) risk exposure. Our Fama and MacBeth (1973) cross-section regressions indicate that, relative to firms in the highest CRS quintile, European and US firms in the lowest CRS quintile offer additional annual returns, amounting to around 4.2% and 4.4%, respectively.

Finally, we document how COP21 has drawn investor attention to climate-related risks. In the more climate-aware European markets, mispricing effects are corrected by reducing (increasing) the value of companies with high (low) exposure. However, in US markets the return spread between less and more vulnerable firms remains unchanged to any significant degree.

CRediT authorship contribution statement

Juan C. Reboredo: Conceptualization, Methodology, Software. **Andrea Ugolini:** Conceptualization, Methodology, Software.

Data availability

Data will be made available on request.

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