The Double-Edged Sword of Firm's Net Zero Commitment on the Carbon Risk Premium

Keith Jin Deng Chan, Wilson Tsz Shing Wan*

Abstract

This article theoretically and empirically shows that a net zero commitment is a double-edged sword from a firm's cost of equity perspective. To mitigate the irreversible impact of global warming, increasing numbers of firms have declared net zero commitments. Our theoretical model elucidates the relationship between a firm's transition ambition, transition readiness, and enterprise value. Empirically, by estimating the carbon risk premium across 1,100 listed firms that have declared a net zero commitment by end-December 2022 worldwide, we find the latter may increase or decrease a firm's carbon risk premium depending on its transition readiness. The empirical results are in line with our theory and cannot solely be explained by the green preference of investors nor the discounted transition credibility of high-emitting firms. Besides, we show that institutional investors effectively channel carbon risk into the equity market by divesting from high-emitting firms that have declared net zero commitment.

Keywords: Carbon emissions; Climate change, Net zero commitment, Stock returns, Institutional investors

JEL: G12, G15, G23, G30, M14

Chan (corresponding author), keithchan@ust.hk, The Hong Kong University of Science and Technology; Wan, tswan@connect.ust.hk, The Hong Kong University of Science and Technology. We thank Edrick Lam for excellent research assistance. We thank Darwin Choi; Anna Dos; Alex He; Sunny Huang; Keith Law; Quentin Moreau; Matteo Pasquino; Marlene Renkel; Conor Walsh; Simon Xu; Chu Zhang; Junjie Zhang; Zoey Yiyuan Zhou; conference participants at the 2025 E-axes Young Scholars Webinars, the 2024 Adam Smith Sustainability Conference & Annual Conference of the British Accounting Review, the 2024 Conference on Sustainable Banking & Finance, the 2024 International Society for the Advancement of Financial Economics Annual Meeting, the 2024 Modern Finance Conference, the 2024 Shanghai-Edinburgh-London-Cape Town Green Finance and Accounting Conference, the 2024 The Hong Kong University of Science and Technology (Guangzhou) International Workshop on Regional Air Quality Management in Rapidly Developing Economic Regions; seminar participants at The Hong Kong University of Science and Technology for many helpful suggestions. This paper has received the Honorable Mention for the 2024 E-axes Forum Research Prize. This research was supported by the theme-based research scheme (TRS) 2021/22 by the Research Grants Council (RGC) of the Hong Kong Government, entitled "Developing Hong Kong as a Global Green Finance Centre" (project no. T31-603/21-N) and the Hong Kong University of Science and Technology Institute for Emerging Market Studies with support from EY. We have no potential conflicts of interest. All errors are ours.

I. Introduction

Finance theory has long recognized the relationship between cross-sectional stock returns and various risk factors, such as market performance, size, book-to-market ratio, profitability, momentum, volatility, and other firm-specific characteristics. Since the Paris Agreement in December 2015, there has been a growing emphasis on a new and significant risk factor: carbon risk. The Paris Agreement set the goal of limiting global temperature increase to well below 2°C above pre-industrial levels and pursuing efforts to limit it to 1.5°C above pre-industrial levels. This has led governments to implement more stringent climate policies to curb greenhouse gas (GHG) emissions. The Agreement also raised global awareness of the urgency of addressing climate change. In financial markets, institutional investors and asset managers have started to incorporate firms' GHG emissions in their investment decisions. Given the combined pressure from governments, the public, and financial market participants, firms' GHG emissions have become a new source of risk for investors.

Firms' GHG emissions can affect stock returns through various channels. First, governments may implement climate policies, such as carbon pricing, to penalize firms for excessive GHG emissions. Second, increasing climate awareness could reduce consumers' demand for products from high-emitting firms. Third, there is growing evidence that firms with greater climate risk exposure incur higher costs of capital from banks and investors. Fourth, higher GHG emissions imply higher future abatement cost for firms. These factors could negatively impact firms' cash flows, profitability, and valuations, especially for firms with disproportionately high GHG emissions. Since Bolton and Kacperczyk (2021), which examined the association between firms' carbon emissions and their stock returns in a sample of US-listed companies, the literature has framed carbon risk as an important risk factor in explaining the variation in cross-sectional stock returns. Forward-looking investors demand a larger premium for holding the stocks of high-emitting firms due to the greater carbon risk exposure. Higher GHG emissions are therefore expected to be associated with higher stock returns.

Recognizing that net zero is the only way to curb global warming (Intergovernmental Panel on Climate Change, 2018; Net Zero Climate, 2023), an increasing number of firms have committed to achieving net zero emissions by a set deadline. According to Net Zero Tracker,[1] more than half of the world's largest 2,000 publicly listed companies by revenue have already made such commitments by end-December 2022. Intuitively, declaring net zero commitment

[1] See https://zerotracker.net/

(NZC) sends an informative signal to the market which could alter a firm's carbon risk premium. As shown in Bolton and Kacperczyk (2024), only firms that make the most ambitious commitments tend to have lower emissions. Compared to other general green commitments that firms make to GHG emissions reduction, a NZC is regarded as the most ambitious as firms declaring a NZC has to fulfil their specific numeric targets and deadlines. As such, compared to other general green commitment, a NZC can better shape investors' perceptions of the firm's future GHG trajectory, as well as the associated costs and benefits, including the realization of abatement costs and reduced exposure to climate-related risks within the firm's GHG inventory.

However, the net impact on the carbon risk premium remains ambiguous. On the one hand, if a firm has sufficient capacity to achieve low-carbon transition in a cost-efficient manner, investors may perceive the firm's transition ambition as desirable. On the other hand, if a firm is located in a market with loose climate policies, investors may view the firm's transition ambition as suboptimal after weighing the associated abatement costs and benefits. Thus, the impact of NZC on a firm's carbon risk premium is predicated on whether its transition ambition is matched by its transition readiness.

A better understanding of carbon risk premium is of high concern to policymakers. For example, a rise in carbon risk premium could lead to a sharp reduction in asset prices, posing volatility in financial markets. It might also result in stronger co-movement of asset prices, challenging market participants' ability to diversify their carbon risk exposure. Building on the small but rapidly growing literature on carbon risk premium, we investigate the impact of NZC on carbon risk premium. We first develop a microeconomic model to investigate the theoretical relationships between a firm's transition ambition, transition readiness, and its enterprise value. We then empirically test these theoretical predictions using a sample of over 1,100 of the largest publicly listed firms by revenues across 49 countries that had declared a NZC by the end-December 2022. This sample represents more than half of the total market capitalization of stocks listed worldwide as of that date. Our main analysis focuses on the period following the Paris Agreement from 2016 to 2022, as the Paris Agreement has heightened the prominence of the climate debate globally and increased both firms' and nations' ambitions for transition moving forward. Following Bolton and Kacperczyk (2023), we utilize the granularity of firm-level observations with various fixed effects to overcome the challenges of endogeneity and identification. To the best of our knowledge, this is the first study to demonstrate how the size and the sign of the carbon risk premium could be altered by firms' NZC.

Three striking results emerge from our empirical analysis. First, we find that a positive association between stock returns and a firm's GHG emission intensity, measured as the ratio of total GHG emissions to sales revenue. This result is statistically and economically significant: a 1% increase in GHG emission intensity is associated with a 1.7% increase in annualized stock returns. Our result is opposite to previous studies by Bolton and Kacperczyk (2021) and Bolton and Kacperczyk (2023), which found a positive association between levels of GHG emissions and stock returns. However, the sample used in our analysis is different, as we study the sample of firms who have declared their NZC by end-December 2022, which are mostly the largest firms by sales revenues in the world, in contrast to all listed firms in the US as in Bolton and Kacperczyk (2021) and all listed firms globally as in Bolton and Kacperczyk (2023), in which climate issues might not be most of the firms' agenda. Our analysis focuses on the implications for the cost of capital following the announcement of NZC by these climate-conscious segments. Investors of these more climate-conscious firms may be more focused on carbon efficiency rather than absolute emission levels. This is supported by Aswani, Raghunandan, and Rajgopal (2023) and Zhang (2024) which argued that emission intensity could be more informative for comparisons across firms, and Hartzmark and Shue (2023) which asserted that investors predominantly focus on carbon intensity for net zero investments. As such, not surprisingly, GHG emissions intensity can play an important role in pricing carbon risk.

Second, we find that a firm's carbon risk premium does not significantly change, on average, after it declares NZC. However, the impact of NZC on carbon risk premium varies substantially with a firm's transition readiness. Specifically, we find that a firm's carbon risk premium is likely to increase (decrease) after NZC declaration if the firm is in a country with high (low) energy use per capita, low (high) renewable electricity output, high (low) policy-driven trend in CO_2 per unit of gross domestic product (GDP), low (high) share of CO_2 covered by a carbon price, or the firm has a low (high) environmental pillar score, and has (does not have) a golden parachutes rule. These findings indicate that the impact of NZC hinges on the firm's transition capacity, transition urgency, and the discount rates of its investors. Without sufficient transition readiness, investors perceive strong transition ambition as at variance with the long-term profit maximization of the firm, and hence declaring NZC may backfire. To facilitate a smooth and healthy low-carbon transition, policymakers should closely monitor firms' NZC declarations, since the accumulation of carbon risk premia could pose challenges to financial stability when climate shocks emerge.

Third, we find that institutional investors have a significant role in pricing carbon risk in stock markets. In line with the findings of Bolton and Kacperczyk (2021), we find that institutional investors tend to divest from firms with high GHG emission intensity. This relationship is statistically and economically significant: a 1% increase in GHG emission intensity is associated with a 1.36% decrease in institutional ownership. Additionally, we find that this reduction escalates to 1.71% for firms that have declared a NZC. Furthermore, we find that firms with larger institutional ownership are conferred larger carbon risk premia. Overall, these findings suggest that institutional investors are more likely to divest from high-emission firms, particularly those that have declared NZC, due to the anticipated abatement costs that could negatively impact their portfolio returns.

Our paper makes three significant contributions to the literature. First, our paper sheds light on the determinants of carbon risk pricing. Existing studies have mainly focused on the existence of the carbon risk premium, while largely overlooking the analysis of their determinants. In light of the importance of corporate NZC in mitigating climate change, we have identified a set of firm-, market-, and country-level factors which can mediate its effect on carbon risk pricing.

The second contribution of our paper is to propose a novel mechanism for how corporate climate risk can be financially material to investors. Existing studies have mainly hypothesized that the lower returns of green assets are due to some investors' green preference, causing them to pay higher prices for green assets. As such, the risk premium for green assets is generally smaller than that for brown assets. This preference-based explanation, however, has limited predictive power. In contrast, we show that a diverse set of investors' behaviour can be rationalized through an intertemporal cost-benefit analysis. Indeed, our theory generates richer predictions and can explain a more diverse set of green asset pricing phenomena. Furthermore, our empirical analysis also falsifies the hypothesis that investors simply discount the credibility of NZC declarations made by high-emitting firms.

The final contribution of our paper is to uncover institutional investors' investment strategies towards firms with NZC. Given the important role of institutional investors in shaping firms' behaviors, directing international capital flows, and facilitating price discovery, our findings on how a firm's NZC affects their investment decisions could provide important policy implications for government to expand the size and reduce volatilities of institutional investors flows, ultimately supporting the broader development of the financial market.

Similar to other studies on asset pricing, a potential challenge is that our cross-country analysis of the impact of NZC declaration on carbon risk premium may be subject to endogeneity issues, given that these variables are not perfectly randomly assigned. We have, however, employed two strategies to address these challenges. First, we exploit variations in firm-, industry-, and country-level characteristics to identify the impact of NZC declaration on the carbon risk premium. Combined with the use of various fixed effects, this granular firm-level data allows us to better isolate the effects of NZC. Second, our sample is primarily selected from firms' revenues, rather than on the dependent variable, i.e., stock returns. Since the correlation between revenues and stock returns in our sample is not significant, the problem of endogenous sample selection is mitigated in this study.

The remainder of this paper is organized as follows. Section 2 reviews the related literature, Section 3 describes and discusses the theoretical framework, Section 4 describes the data and provides summary statistics, Section 5 discusses the results, and Section 6 concludes.

II. Related Literature

Our work is related to the rapidly growing literature on the asset pricing implications of environment-related metrics. Early evidence has revealed a negative association between a firm's environmental performance and its cost of capital. For instance, El Ghoul et al. (2011) document that firms with better corporate social responsibility (CSR) scores have a lower cost of equity. Chava (2014) reveals that firms deriving substantial revenues from the sale of fossil fuels are associated with higher costs of capital. More recently, studies have uncovered a positive association between stock returns and firms' climate risk exposure. Oestreich and Tsiakas (2015) document the existence of a carbon risk factor that could explain part of the cross-sectional variation in stock returns in a sample of 65 German-listed companies. Bansal, Kiku, and Ochoa (2019) show that long-run temperature fluctuations induce a positive risk premium in stock markets across 48 countries. Engle et al. (2020) document that portfolios of stocks constructed based on firms' environmental pillar scores could potentially be used to hedge against climate change news risk. Wen, Wu, and Gong (2020) find that the carbon risk premium in the Chinese stock market increased after China's carbon emissions trading market was established. Gorgen et al. (2020) show, in the sample of more than 26,000 firms worldwide, brown firms are associated with greater average returns than green firms. Alessi, Ossola and Panzica (2021) reveal that investors in European markets accept lower returns to hold greener stocks. Rationalized by the preference for green assets, Pastor, Stambaugh, and Taylor (2021) show that green assets have low expected returns because investors enjoy holding them. Focusing on the US stock market, Bolton and Kacperczyk (2021) find evidence of a significant carbon risk premium for firms with higher total carbon dioxide emissions. Ilhan, Sautner, and Vilkov (2021) find that climate policy uncertainty is priced in the option market, in which the price of option protection against downside tail risks is greater for firms with more carbon-intense business models. Pastor, Stambaugh and Taylor (2022) show that although green stocks outperform brown stocks as climate concerns strengthen, the expected returns for green stocks are still lower than those for brown stocks. Hsu, Li, and Tsou (2023) show that firms in the US with higher toxic emission intensities are associated with higher stock returns, as they are more exposed to regulatory risks. Furthermore, they also build a general equilibrium asset pricing model to rationalize how a firm's exposure to environmental policy regime alters its equity risk premium. Hong, Wang, and Yang (2023) show that unexpected natural disasters associated with global warming has led to a higher risk premium in the stock market. Faccini, Matin and Skiadopoulos (2023) find that climate policy factors are priced in the US stock market. Reshetnikova et al. (2023) find that a positive and statistically significant carbon risk premium exists in the Russian stock market. Covering more than 14,400 firms in 77 countries, Bolton and Kacperczyk (2023) find a widespread carbon risk premium in all sectors across Asia, Europe and North America following the announcement of the Paris Agreement. Cenedese, Han, and Kacperczyk (2023) document that firms with better alignment on net zero targets have lower expected returns. Wu and Wan (2023) show that the phenomenon of positive climate risk premium also exists in the country-level stock market indices, and such premium would increase the co-movement of stock market returns. Edenhofer, Lessmann, and Tahri (2024) document that carbon risk premium could be affected by carbon pricing. Nguyen, Truong, and Zhang (2025) find that firms with high carbon emissions experience an increase in the costs of equity.[2]

A higher carbon risk premium suggests that asset prices become more vulnerable to carbon-related shocks. The literature has also explored similar equity pricing behavior driven by unexpected climate shocks. Choi, Gao, and Jiang (2020) show that, compared to stocks of firms with lower carbon emissions, stocks of carbon-intensive firms underperform in abnormally warm weather. Ramelli, Ossola, and Rancan (2021) show that carbon-intensive firms in Europe recorded substantially negative abnormal returns around the first Global Climate Strike in 2019. Ardia et al. (2022) find that on days with an unexpected increase in climate change concerns, among the sample of S&P 500 companies, green firms' stock prices tend to increase, whereas brown firms' stock prices decrease. While existing literature tries to study the asset pricing implications of climate risk exposure either using the sample of all listed firms globally or just selected markets, our study contributes to the literature by examining the

[2] The existing literature has also explored the relationship between climate risk and other financial assets classes, including corporate bonds (for example, Huynh and Xia, 2020; Duan, Li, and Wen, 2023), municipal bonds (for example, Painter, 2020; Goldsmith-Pinkham et al.,2023), syndicated loans (for example, Ehlers, Packer, and De Greiff, 2022; Ho and Wong, 2023; Delis et al., 2024) and real estate assets (for example, Bernstein, Gustafson, and Lewis, 2019; Baldauf, Garlappi, and Yannelis, 2020; Giglio et al., 2021; Wong, Ka, and Ng, 2023).

segment of the largest firms worldwide. This group is globally systemically important in terms of both financial market stability and climate considerations.

The existing literature also attempts to relate a firm's commitment to its green performance and stock returns. However, the findings are mixed. At the regional level, Peterson (2022) finds no statistically significant enhanced premium in stock valuation for a sample of large-cap, investor-owned utilities in the US who made bold commitments to achieve carbon neutrality. Liu et al. (2022) show that solid green commitment could reduce stock price crash risk in a sample of listed firms in China. In a sample of 166 listed UK and US firms, Xie et al. (2023) document that firms experience losses in market value from committing to carbon neutrality. However, they also find that better ESG performance could mitigate such adverse market reactions. These mixed findings suggest that the relationship between a firm's green commitment and its asset pricing is likely to vary across different markets and sectors. We contribute to this strand of literature by studying how a firm's NZC is associated with its stock returns via the carbon risk premium channel. More importantly, we explore how this relationship varies based on firm-specific, market-specific, and country-specific characteristics, using a sample of climate-conscious firms globally.[3]

Our work is also related to the literature on climate-related investment strategies. Existing studies have examined how investors, especially institutional investors, have incorporated climate considerations into their portfolio decisions. Heinkel, Kraus & Zechner (2001) show that firms with higher emissions could generate higher stock returns due to divestments from investors. Hartzmark and Sussman (2019) find that both institutional and retail investors are more willing to hold stocks of socially responsible firms. Focusing on institutional investors, Dyck et al. (2019) show a positive relationship between institutional ownership and a firm's CSR performance. Nofsinger, Sulaeman, and Varma (2019) find that institutional investors under-weigh stocks with negative environmental and social indicators. Krueger, Sautner, and Starks (2020) show that institutional investors believe that carbon emissions have become a material financial risk, and that carbon risk is priced in the market. Monasterolo and De Angelis (2020) find that the weight of low-carbon indices within optimal portfolios tends to increase after the Paris Agreement. Bolton and Kacperczyk (2021) show

[3] Existing studies also investigate the creditability of green commitment. For example, Bolton and Kacperczyk (2024) document that firms committed to reducing their carbon emissions subsequently reduce their emissions; however, the aggregate impact has yet to be limited to tackling the climate problems. Chan, Cheung, and Shen (2024) show that a firm's net zero decision might not be optimal for firms with a sufficiently high stock of GHG emissions. Our paper distinguishes itself by demonstrating that NZC can either increase or decrease a firm's value, depending on whether such a commitment is optimal for the firm. The effects on the firm extend beyond the credibility of the commitment per se.

that institutional investors tend to divest from firms with higher Scope 1 emission intensity, primarily in high-emitting sectors. Garel and Petit-Romec (2021) show that firms with responsible environmental strategies experienced better stock returns during the COVID-19 crisis, and the association was stronger for firms with greater long-term institutional investor ownership. Pedersen, Fitzgibbons, and Pomorski (2021) document a negative association between institutional ownership and a firm's CO_2 intensity. Choi et al. (2021) find that financial institutions reduced their exposure to stocks of companies in high-emission industries after 2015, especially for those in high-climate-awareness countries. Avramov et al. (2022) reveal that a firm's ESG uncertainty could lead institutional investors to decrease their demand for its stock. Safiullah, Alam, and Islam (2022) document that institutional investors have promoted firm-level emissions abatement, and the result is more pronounced for firms with more independent, long-term institutional ownership. Kordsachia, Focke, and Valte (2022) show that sustainable institutional ownership is positively associated with a firm's environmental performance and its carbon disclosure. De Angelis, Tankov, and Zerbib (2022) show that green investors spur firms to reduce their carbon emissions by increasing the costs of capital for the most carbon-intensive companies. Cao et al. (2022) find that institutional investors are more willing to sell low-CSR stocks and more reluctant to sell high-CSR stocks. Kahn, Matsusaka, and Shu (2023) show that firms reduced their GHG emissions when stock ownership by green funds increases. Cohen, Kadach, and Ormazabal (2023) find that institutional investors are more likely to engage with and divest from top carbon emitters. Overall, these studies generally conclude that institutional investors tend to divest from firms with poorer green performance. We contribute to this literature by enhancing our understanding about how institutional investors alter their investment strategy in response to a firm's NZC, and how this interacts with the firm's green performance.

In summary, the abovementioned studies demonstrate that stock market investors do price climate risk into stock returns. In particular, firms with greater exposure to climate risk have higher average stock returns, and hence the accumulation of climate risk premium might trigger abrupt asset price corrections during climate shocks. Existing studies generally rationalize the lower risk premium of green assets by the green preference hypothesis. However, this hypothesis has limited predictive power, as it implies that green assets always yield less than expected. Motivated by Hsu, Li, and Tsou (2023), which adopted a general equilibrium model to explain the pollution risk premium, our paper differs from the green preference hypothesis by providing an alternative explanation of how climate risk can be financially material and how rational investors price climate risk using intertemporal cost-benefit analysis. As such, the predictive power of our model is much stronger.

In addition, the literature shows that institutional investors play a significant role in shaping the overall climate investment universe. Despite the importance of corporate NZC, our understanding of their interaction with climate risk premium at a global level is lacking. By using a sample of more than 1,100 listed firms from 49 countries that have declared their NZC by end-December 2022, our study contributes to the literature by exploring how a firm's declaration of NZC could alter its carbon risk premium, and the role of institutional investors in channeling such risk to stock returns.

III. Theoretical Framework

This section introduces a microeconomic model to analyze how a firm's declaration of its NZC affects investors' evaluation of its carbon risk and hence its enterprise value. Existing literature, such as Pastor, Stambaugh, and Taylor (2021) and Pastor, Stambaugh and Taylor (2022) predict that green assets have lower expected returns than brown due to investors' green taste and green assets is a better hedge against climate risk. Yet, their models have not taken the financial materiality of climate risk into account. In contrast, our model, adopted from Chan, Cheung, and Shen (2024) with modifications, rationalizes the change in carbon risk premium, by explicating the relationship between the carbon risk and the enterprise value of a firm. As such, investors' behavior can be rationalized using cost benefit analysis without relying on the green preference. The prediction of our model in turn is much richer and the theory can explain more diverse pricing phenomenon.

The parameters measuring the firm's transition urgency β, transition capacity κ, and transition ambition ϕ are all from the (representative) investor's perspective to capture the idea that the carbon risk premium is driven by investor beliefs. Time is continuous and denoted by $t \geq 0$. Let $x(t)$ and $g(t)$ be the GHG emission intensity and gross profit (before accounting for the abatement costs and carbon risks pertaining to its emission intensity) of the firm at time t respectively. The initial emission intensity is $x(0) = x_0 > 0$. Apart from its GHG emission intensity, the firm's carbon risk is also proportional to the transition urgency perceived by the investor, which is measured as the parameter $\beta > 0$. The dollar value of the carbon risk borne at time t is then $\beta x(t)$. Nevertheless, the firm can choose to decarbonize its value chain.

Let $u(t) \coloneqq -\dot{x}(t)$ denote the decarbonization rate of the firm at time t. For simplicity, we impose the constraint $u(t) \geq 0$ to rule out recarbonization. For some parameter $\kappa > 0$, let

$\frac{1}{2\kappa}u(t)^2$ be the abatement cost borne by the firm if its decarbonization rate is $u(t)$ at time t. The convexity of the cost function reflects the law of diminishing marginal returns of the abatement efforts. κ captures the firm's transition capacity perceived by the investor in the sense that a higher κ is associated with a lower marginal cost of abatement.

In line with the Paris Agreement net zero pledges, the firm in the model has a "deadline" to attain net zero at $t = 1$ such that it is endowed with only a unit of time to decarbonize. To render the deadline analytically meaningful, set $u(t) \equiv 0$ for $t > 1$. Since the model aims to capture the declaration of NZC as a communication device for the firm's transition ambition, let $x(1) \equiv x_1 \in (0, x_0)$ be the emission intensity target perceived by the investor. Moreover, as the ambition of a target x_1 is relative to the initial emission intensity x_0, we define the transition ambition parameter $\phi \equiv 1 - x_1/x_0$. In the limit, $\phi = 0$ means that the firm maintains its status quo emission intensity $x_1 = x_0$, whereas $\phi = 1$ means that it attains net zero $x_1 = 0$.

Based on the above setting, the net profit of firm $\pi(t)$ at time t can be defined as follows, where $\mathbb{1}$ is the indicator function.

$$\pi(t) = g(t) - \beta x(t) - \frac{\mathbb{1}_{t\in[0,1]}}{2\kappa}\, u(t)^2$$

In this dynamic set-up, the investor has a discount rate of $r > 0$ and is concerned with the enterprise value of the firm, which is measured as the net present value of its net profit flows. However, the latter evidently hinges on the transition pathway $u(t)$ chosen by the firm. We assume that the investor evaluates the latter by considering the optimal transition pathway, allowing us to focus on the effects of the parameters. The optimized enterprise value can then be written as

(P)
$$\mathrm{V} = \max_{\{u(t)\geq 0\}_{t\in[0,1]}} \int_0^\infty e^{-rt}\left(g(t) - \beta x(t) - \frac{\mathbb{1}_{t\in[0,1]}}{2\kappa}u(t)^2\right)dt$$

This completes the description of the microeconomic model. Next, we proceed to analyze the firm's optimal transition pathway and its resulting enterprise value. To facilitate the analysis, define the function

$$F(z) \coloneqq 1 + z + W_0\left(-e^{-(1+z)}\right)$$

where W_0 is the principal branch of the Lambert W function.

Proposition 1: Let $\tau = \min\left\{1, \frac{1}{r}F\left(\frac{r^2\phi x_0}{\beta\kappa}\right)\right\}$. The optimal emissions pathway of the firm is

$$x^*(t) = \begin{cases} x_0 - \frac{\beta\kappa}{r}t - \left(\frac{e^{rt}-1}{e^{r\tau}-1}\right)\left(\phi x_0 - \frac{\beta\kappa}{r}\tau\right) & \text{if } t < \tau \\ x_1 & \text{if } t \geq \tau \end{cases}$$

Moreover, $\tau < 1$ if and only if $r + e^{-r} > 1 + \frac{r^2\phi x_0}{\beta\kappa}$.

Proof: See Appendix A1.

Proposition 1 shows that the firm may optimally exhibit two types of transition behavior: (a) attain its ambition at time $t = 1$ on the deadline, or (b) attain its ambition at time $t = \tau < 1$ ahead of the deadline. The transition pathway of case (b) is characterized by the condition $r + e^{-r} > 1 + \frac{r^2\phi x_0}{\beta\kappa}$. In other words, the firm's transition ambition ϕ is so low relative to its transition capacity κ and urgency β that it halts decarbonization ahead of the deadline ($u^*(t) = -\dot{x}^*(t) = 0$ for $t \in [\tau, 1]$). Whereas case (b) is theoretically possible, as our sample covers the most climate-conscious 1,177 companies by revenues that have declared NZC, the probability for these firms in the globe to cheap talks is slim. Therefore, we reckon that it is not representative of investors' expectations. Nevertheless, for completeness, we present the findings in both cases.

The present model aims to capture the declaration of NZC as a communication device for the firm's transition ambition. Thus, the effect of the former is modelled as an upwards adjustment of the firm's transition ambition ϕ perceived by the investor. In the following, we capture the net zero commitment premium and the carbon risk premium of the firm as the decrease in its optimized enterprise value resulting from an increase in its perceived transition ambition ϕ and initial emission intensity x_0, respectively.

Proposition 2: Suppose $r + e^{-r} < 1 + \frac{r^2\phi x_0}{\beta\kappa}$. The optimized enterprise value of the firm is

$$V_a \equiv \int_0^\infty e^{-rt}g(t)dt - \frac{\beta x_0}{r} - \frac{r^4\phi^2x_0^2 - 2\beta\kappa r^3\phi x_0 + \beta^2\kappa^2(2 + r^2 - e^r - e^{-r})}{2\kappa r^3(e^r - 1)}$$

Moreover, the following statements hold for the firm.

(i) Its carbon risk premium is positive:

$$\frac{\partial V_a}{\partial x_0} < 0$$

(ii) Declaring a NZC raises its optimized enterprise value if and only if its transition capacity and urgency are sufficiently high relative to its transition ambition:

$$\frac{\partial V_a}{\partial \phi} > 0 \quad \Leftrightarrow \quad \frac{r\phi x_0}{\beta\kappa} < 1$$

(iii) Its declaration of a NZC raises its carbon risk premium if and only if its transition capacity and urgency are sufficiently low relative to its transition ambition:

$$\frac{\partial^2 V_a}{\partial \phi \partial x_0} < 0 \quad \Leftrightarrow \quad \frac{r\phi x_0}{\beta\kappa} > \frac{1}{2}$$

Proof: See Appendix A.2.

Proposition 2 captures how a firm's enterprise value varies with its initial GHG emission intensity and transition ambition if it belongs to the type that optimally decarbonizes until and only until the deadline. As expected, statement (i) suggests a carbon risk premium exists. However, as suggested by statement (ii), declaring NZC may reduce its enterprise value if investors believe that attaining net zero is not a priority or beyond the firm's capacity. As such, statement (iii) shows that such a declaration may also raise the carbon risk premium.

Proposition 3: Suppose $r + e^{-r} > 1 + \frac{r^2\phi x_0}{\beta\kappa}$. With $\tau \equiv \frac{1}{r} F\left(\frac{r^2\phi x_0}{\beta\kappa}\right)$, the optimized enterprise value of the firm is

$$V_b \equiv \int_0^\infty e^{-rt} g(t)dt - \frac{\beta x_0}{r} - \frac{r^4\phi^2 x_0^2 - 2\beta\kappa r^3\tau\phi x_0 + \beta^2\kappa^2(2 + r^2\tau^2 - e^{r\tau} - e^{-r\tau})}{2\kappa r^3(e^{r\tau} - 1)}$$

Moreover, the following statements hold for the firm.

(i) Its carbon risk premium is positive:

$$\frac{\partial V_b}{\partial x_0} < 0$$

(ii) Declaring a NZC raises the optimized enterprise value:

$$\frac{\partial V_b}{\partial \phi} > 0$$

(iii) Declaring a NZC raises its carbon risk premium if and only if its transition capacity and urgency are sufficiently low relative to its transition ambition:

$$\frac{\partial^2 V_b}{\partial \phi \partial x_0} < 0 \quad \Leftrightarrow \frac{r^2 x_0 \phi}{\beta\kappa} > \; 1 + \frac{1}{2} W_0(-2e^{-2})$$

Proof: See Appendix A.3.

Proposition 3 is similar to Proposition 2, except that the former focuses on firms whose transition ambition is so low relative to their transition capacity κ and urgency β. Statement (i) suggests that the carbon risk premium is still positive. However, compared to type of firm in Proposition 2, for this type of firms, statement (ii) shows that elevating the transition ambition perceived by investors via a declaration of NZC can unambiguously increase their enterprise value as the declaration signal a strong increase in transition ambition. Nevertheless, similar to the type of firms in Proposition 2, statement (iii) shows that declaring NZC may elevate the carbon risk premium at the same time.

Propositions 2 and 3 suggest that declaring NZC could increase or decrease the firm's carbon risk premium, depending on its transition capacity and urgency. The higher the firm's transition capacity and urgency, the more desirable investors tend to perceive its transition ambition, and hence more likelihood a declaration of NZC will lower its carbon risk premium. To empirically test the prediction of our theoretical framework, in the next sections, we explore the impact of firm's NZC declaration on its carbon risk premium using a sample of a cross-section of more than 1,100 listed firms in 49 countries over the period from 2016 to 2022.

IV. Data and Sample

Our primary database covers the period from 2016 to 2022 and integrates data from six sources: Trucost, which provides annual information on firm-level GHG emissions; Science Based Targets initiative, which provides data on companies that have committed to net-zero targets. S&P Capital IQ Pro, which offers data on firms' financial statements, including balance sheets, income statements, and annual reports; and publicly available corporate sustainability disclosures, such as ESG reports, CDP questionnaires, and TCFD reports, which allow us to extract information about the timing of firms' NZC declaration; Bloomberg, which supplies data on stock returns and institutional ownerships. Our sample comprises 1,177 firms that have declared NZC by the end of December 2022, representing approximately 52% of the total market capitalization of stocks listed worldwide as of that date. We match the data using firm's Ticker. Moreover, we augment the data with country-level variables from Our World in Data, which provides annual data on energy use per capita, renewable electricity output as a percentage of total electricity output by countries, and coverage of carbon pricing, as well as a dataset from the Yale Center for Environmental Law & Policy of the policy-driven trends in country-level CO_2 emission intensity, which is adjusted for economic fluctuations and resulting solely from government policies.

A. Data on firms' environmental performance and net zero commitment

We sourced the firms' emissions data from Trucost, which collects firms' environmental data from a variety of publicly disclosed sources, including annual reports, 10-K reports, SEC filings, CSR reports, sustainability reports, and ESG reports. In the absence of public disclosures, Trucost provides data estimated using its environmentally extended input-output model.[4] Following the GHG Protocol,[5] Trucost provided GHG emissions data across all three scopes. Scope 1 emissions are from directly emitting sources owned or controlled by a firm, such as the internal combustion engines of a trucking firm. Scope 2 emissions are from the consumption of energy generated upstream from a firm's direct operation, such as purchased electricity and steam. Scope 3 emissions cover all other emissions associated with a firm's operations that are not directly owned or controlled by the company, including emissions in the company's supply chain and downstream. All three scopes of GHG emissions are reported in units of tons of GHG emitted in a year.

Apart from the level of GHG emissions, Trucost also provides the level of all three scopes of GHG emissions normalized by a company's annual consolidated revenues, which is also known as GHG emission intensity. The latter allows for meaningful comparisons of emissions performance within and across different industries, providing a standardized measure of a firm's carbon efficiency. All three scopes are reported in units of tons of GHG emitted per millions of US dollars of revenue. Since the three scopes of emissions capture different dimensions of emissions performance, we use the aggregate of all three scopes of emissions to measure a firm's GHG performance. A potential caveat is that Scope 3 emissions data are subject to a less comprehensive standardization and assessment compared to Scope 1 and Scope 2 emissions (Ho and Wong, 2023; Leung, Wan, and Wong, 2023; Chan and Wan, 2024). However, since our sample covers mainlythe largest listed firms globally, the probability of substantial measurement errors is relatively low. Furthermore, as shown in the summary statistics, the relative importance of Scope 3 emissions is not lower than that of Scope

[4] One potential concern is whether the estimated emissions data by Trucost can reasonably reflect the genuine emissions of a firm. For instance, Chan and Wan (2024) document that only about one-fourth of emissions data in Trucost are firm-disclosed data whereas three-fourth of them are estimated. Aswani, Raghunandan, and Rajgopal (2024) show that the Trucost estimates could be systematically different from firm-disclosed emissions. This concern, however, is insignificant in our study in the sense that we only select the largest companies worldwide. As such, most of the emissions data in our sample are firm-disclosed data. Specifically, more than 90% of Scope 1 and 2 emissions are firm-disclosed data whereas more than 60% for Scope 3.

[5] See https://ghgprotocol.org/

1 and Scope 2 emissions. Therefore, including Scope 3 provides us with a more accurate picture of a firm's overall GHG performance.[6]

In addition to the GHG data, Trucost covers a broad range of financially material environmental factors by providing firm-level environmental pillar scores, as well as other indicators, including social pillar scores, and governance and economic pillar scores. All these pillar scores range from 0 to 100, with a higher score generally indicating a better performance of the firm in that dimension.[7]

We sourced from Science Based Targets initiative (SBTi) and S&P Capital IQ Pro the firms' NZC data. SBTi is a leading corporate climate action organization that empowers companies and financial institutions around the world to address the climate crisis effectively. By defining and promoting best practices for emissions reductions and net-zero targets grounded in climate science, SBTi develops comprehensive standards, tools, and guidance. These resources enable firms to establish science-based targets that align with the latest climate research, fostering accountability and driving meaningful action toward a sustainable future. The SBTi has also gathered data on companies that have committed to net-zero targets. By the end of 2022, a total of 949 firms had set science-based emissions reduction targets aligned with the 1.5°C pathway or had established net-zero science-based targets. Among these 949 firms, 67 of them are excluded in our sample as GHG emissions data are not available.

To enhance our dataset on firms that have declared NZC not captured by the SBTi, we supplement our information with data from S&P Capital IQ. S&P Capital IQ Pro collects all publicly disclosed filings and reports of publicly listed firms, including annual reports, 10-K reports, CSR reports, sustainability reports, environmental reports, ESG reports, CDP questionnaires, and TCFD disclosures. We reviewed all these publicly disclosed filings and reports to identify the first instance where a firm declared its NZC. Given that firms may use a range of similar terms interchangeably, such as "net zero", such as "net zero", "zero emissions", "zero carbon", "climate neutral", "climate positive", "carbon neutrality", "carbon negative",

[6] Because Trucost has only recently started assembling downstream Scope 3 emissions, the gaps in the data are numerous. As such, throughout our study, Scope 3 refers to upstream Scope 3. The same treatment was also adopted in Bolton and Kacperczyk (2021), Bolton and Kacperczyk (2023), Dai et al. (2024).

[7] The correlation between the environmental pillar score and GHG emissions is not as high as one might have expected due to two reasons. First, apart from factors related to GHG emissions, the environmental pillar score represents a wide range of environmental factors, including biodiversity, climate strategy, waste and water management, etc. Second, the environmental pillar score mainly captures the nonfinancial risks to which a firm is exposed, rather than the climate impact created by the firm. For instance, a large GHG emitters could have a high environmental pillar scores if it promises to decarbonize. In our sample, the correlation between the environmental scores and levels of total GHG emissions is 0.20 whereas that between the environmental pillar scores and the GHG emissions intensities is 0.03.

“net negative”, “1.5-degree target”, “science-based target”, etc., we captured the initial appearance of any of these phrases to determine the date of NZC declaration. Our final sample consists of 1,177 firms that have declared NZC by the end of December 2022, representing approximately 52% of the total market capitalization of stocks listed worldwide as of that date. For the sake of quantitative analysis, we define a dummy variable $D_{i,t}^{NZ}$ which equals one if firm i has declared NZC on or before time t and equals 0 otherwise.

Panel A of Table 1 reports the summary statistics for firms’ environmental performance. The levels of both total emissions and emission intensity are normalized using the natural log scale. The log of the total GHG emissions across all three scopes (LOG GHG) has a sample mean of 14.54 and a standard deviation of 1.97. Analyzing the GHG emissions by scope, we find that Scope 3 emissions constitute the largest component of the average firm’s total emissions footprint. For emissions intensity, the log of the total GHG emission intensity (LOG GHG intensity) has a sample mean of is 5.16 and a standard deviation of 1.34. In addition, the average firm has an environmental pillar score of 57.1. Furthermore, 45% of the observations in our sample has declared NZC.

Figure 1 depicts the cumulative density function of firms declaring NZC. Among the 1,177 firms in our sample, most declared their NZC during 2020 and 2021. For instance, while approximately 20% of the firms had declared NZC by 2019, this proportion surged to over 80% by 2021. Figure 2 reports the regional breakdown of the sample into three regions, namely, North America, Europe and Others, based on a firm’s location.[8] Firms in Europe are leading in NZC, followed by those in North America and Others.

[FIGURE 1 HERE]

[FIGURE 2 HERE]

B. Data on stock returns, institutional ownership, and other control variables

We sourced stock returns and institution ownership information from Bloomberg and other control variables from Bloomberg and S&P Capital IQ Pro. Following Bolton and Kacperczyk (2021), Bolton and Kacperczyk (2023), and Aswani, Raghunandan, and Rajgopal. (2024), our empirical analysis of stock returns employs a monthly measure of returns as a dependent variable. The dependent variable in our cross-sectional return regressions, $RET_{i,t}$, is the monthly return of individual stock i in month t. The monthly return in month t is computed as

[8] In case of multi-national corporations, we rely on the location of its primary business activities.

the log difference between the stock price in t and that in $t-1$. Another dependent variable in our cross-sectional institutional ownership regressions is the percentage of shares of individual stock i owned by institutional investors in month t, $IO_{i,t}$. Following Bolton and Kacperczyk (2023) and Aswani, Raghunandan, and Rajgopal (2024), we include the following control variables in our cross-sectional regressions: $LOGSIZE_{i,t}$, which is the natural log scale of the market capitalization of firm i at the end of year t; $B/M_{i,t}$ which is the book-to-market ratio of firm i at the end of year t; $LEVERAGE_{i,t}$, which is the total debts divided by the total assets of firm i at the end of year t; $MOM_{i,t}$, which is the average of the most recent 12 months' return of stock i leading up to and including month $t-1$; $INVEST/A_{i,t}$, which is firm i's capital expenditures divided by total assets at the end of year t; $HHI_{i,t}$, which is the Herfindahl concentration index of firm i with respect to its industry based on each industry's revenues at the end of year t; $LOGPPE_{i,t}$, which is the natural log scale of property, plant, and equipment of firm i at the end of year t; $ROE_{i,t}$, which is the net income divided by the total equity of firm i at the end of year t; and $VOLAT_{i,t}$, which is the standard deviation of returns based on the past 12 months' return of stock i, leading up to and including month $t-1$. Unlike Bolton and Kacperczyk (2023) and Aswani, Raghunandan, and Rajgopal. (2024), given that our sample consists of mostly the largest listed firms globally, outliers are not significant. Therefore, we did not winsorize our data. In addition, to capture the degree of short-termism of board members, we also include whether the firms have golden parachute rules.[9] Ultimately, our main sample contains 77,701 stock-month observations from January 2016 to December 2022 that cover 1,177 unique firms in 49 countries.

Panel B of Table 1 summarizes all relevant variables used in our cross-sectional analysis. The monthly stock return in our sample has a mean of 0.77% and a standard deviation of 9.06%. Institutional investors hold an average of 69.70% of the shares across the sample. The average market capitalization of the firms is 18.59 trillion in US dollars. The average book-to-market ratio is 0.71 and the leverage ratio is 0.28. The average capital expenditure-to-asset ratio is 0.03. The industry concentration ratio is 2.7%. The average firm has $7.13 trillion in property, plant, and equipment and an ROE of 0.11. Besides, slightly more than half of the sample firms have golden parachute provision in place.

[9] A golden parachute refers to a large financial compensation or substantial benefits guaranteed to company executives upon termination following a merger or takeover, it encourages short termism as it is more difficult for top decision-makers to be quickly replaced due to poor short-term financial performance. Shive and Forster (2020) find that firms with a golden parachute recorded a higher CO_2 emissions compared to firms without a golden parachute.

Furthermore, our analysis incorporates several country-level variables that capture the broader environmental and policy context in which the firms operate. They include energy use per capita, renewable electricity output as a percentage of total electricity output, the trend in CO2 emissions per unit of GDP due to policy metrics, and the share of CO_2 emissions covered by a carbon price. The country-level energy use per capita and renewable electricity output as a percentage of total electricity output are sourced from Our World in Data. The average firm is in a country consuming 4,753 kg of oil equivalent per capita and having 20.4% renewable electricity output to total electricity output. The trend in CO2 emissions per unit of GDP due to policy metrics (thereafter referred to as the policy-driven trend in CO_2 emission intensity) is sourced from the Yale Center for Environmental Law & Policy. This metric tracks the average change in CO_2 emissions per unit of GDP over the past 10 years, with adjustments made to account for fluctuations in the economic business cycles. By isolating the policy impacts, this indicator reflects government efforts to reduce the CO_2 intensity (Wolf, et al., 2022). Finally, we incorporated the share of each country's total CO_2 emissions that are covered by a carbon pricing mechanism. This data, sourced from Our World in Data, provides a measure of the breadth of carbon pricing policies in the countries where our sample firms operate. On average, the firms in our sample are located in countries where 31% of CO_2 emissions are subject to a carbon price.

[TABLE 1 HERE]

We also break down the sample in Table 2 into those before and after NZC declaration. We note that for the observations after declaring NZC, the average GHG emissions level (as well as that of each of the three scopes) is slightly higher compared to period before NZC. However, the average GHG emission intensity (as well as that of each of the three scopes) is slightly lower. In addition, after declaring NZC, the observations have higher environmental pillar scores and lower stock returns and returns on equity. Other firm-level characteristics, such as size, book-to-market ratio, leverage, capital expenditure, and fixed assets, remain quite similar before and after the NZC declaration.

Delving into the country-level context, we find that the sub-sample of observations after declaring NZC, on average, operates in countries with lower energy use per capita, higher share of renewable electricity output, lower policy-driven trend in CO_2 emissions intensity, and higher carbon price coverage. This suggests that firms declaring NZC are operating in an environment that is more associated with low-carbon activities and policies.

[TABLE 2 HERE]

Finally, we report the summary statistics on the potential determinants of firms' declarations of NZC in Table 3. We adopt regression analysis to examine the relationship between the dummy variable of NZC and firms' emissions as well as other firm-level characteristics. Year/month-fixed effects, country-fixed effects and industry-fixed effects (using SIC classification) are also included to capture the differences across countries and industries over time.[10] Columns (1) and (2) measure emission performance by the natural log scale of the total emissions across all three scopes, whereas Columns (3) and (4) use the natural log scale of total emission intensity across all three scopes. Probit and Logit models are employed, as our dependent variable, $D_{i,t}^{NZ}$, is binary.[11]

We first note that the probability of a firm declaring NZC generally decreases with both total GHG emissions and total GHG emission intensity, suggesting that high-emitters and less carbon-efficient firms are less inclined to declare NZC. Concerning firm attributes, we note that the probability of a firm declaring NZC increases with its size, book-to-market ratio, and tangible capital stock. These findings imply that firms declaring NZC often possess stronger fundamental characteristics. The negative coefficient of leverage suggests that firms may have a weaker incentive to utilize leverage for profitability enhancement after NZC declaration, as they might face decreased carbon risk exposure. Investment and ROE exhibit negative relationships with NZC declaration, suggesting high-growth firms may prioritize expansion over carbon efficiency. Industry specialization has a negative coefficient, suggesting that firms declaring NZC are generally less specialized. Institutional ownership has a positive effect on declaring NZC, suggesting that institutional investors could be instrumental in driving firms towards improved environmental performance. Firms declaring NZC exhibit negative coefficients for momentum and volatility, implying their alignment with value stocks rather than high-growth stocks.

[TABLE 3 HERE]

[10] As discussed in Aswani et al. (2023), the choice of industry classification system could yield significantly different results. However, the results are also robust to using other industry classification, including the Trucost industry classification, Bloomberg industry classification system and Global industry classification standard.
[11] For robustness check, we also performed fixed-effects estimations, and the results are similar. For brevity, we do not present here the estimation result of fixed-effects estimations. For interested readers, the results are available on request.

We then run the regression once again without the industry fixed-effects in Columns (5), (6), (7) and (8). We notice that in Columns (5) and (6), high-emitters are still less likely to declare NZC. However, Columns (7) and (8) reflect that less carbon-efficient firms, without limiting to within-industry comparison, are more likely to declare NZC. This contrasts with the within-industry findings, where less carbon-efficient firms were less likely to declare NZC. The results suggest that when compared to the entire sample, less carbon-efficient firms are more likely to declare NZC, whereas within each industry, the less carbon-efficient firms are less likely to make such commitment. In additional, when compared to the entire sample, firms with smaller book-to-market ratio are more likely to declare NZC, whereas leverage, industry specialization and ROE are not as significant in explaining firm's NZC declaration as they are in the within-industry comparisons.

V. Estimation Results

We organize our discussion into three subsections. The first subsection replicates the analysis of Bolton and Kacperczyk (2023) by evaluating the carbon risk premium among the 1,177 firms in our sample. The second subsection explores the impact of NZC on the size and sign of the carbon risk premium. The third subsection investigates the role of institutional investors in channeling the impact of NZC on the carbon risk premium.

A. Carbon Risk Premium

In this section, we present our findings on the carbon risk premium. We begin by specifying the estimation model used to quantify the carbon risk premium. We then report the findings for the full sample. Finally, we show how the carbon risk premium is distributed across different geographical regions.

1. Empirical Specification

Following Bolton and Kacperczyk (2023), we evaluate the carbon risk premium by estimating the following cross-sectional characteristic-based regression which is found to be more appropriate than the risk factor-based approach for a sample with rich cross-sectional variation in firm characteristics:

(1) $$RET_{i,t} = \alpha_0 + \alpha_1 Emissions_{i,t-1} + \alpha_2 Controls_{i,t-1} + \mu_{country} + \delta_{industry} + \gamma_t + \varepsilon_{i,t}$$

The dependent variable $RET_{i,t}$ measures the stock return of firm i in month t. The independent variable $Emissions$ is the generic term representing for $LOG\ CO2$ and $LOG\ CO2\ intensity$. The vector of firm-level controls includes the firm-level variables $LOGSIZE$, B/M, $LEVERAGE$, MOM, $INVEST/A$, HHI, $LOGPPE$, ROE, and $VOLAT$. Both $Emissions$ and the control variables are lagged by 1 month. $\mu_{country}$, $\delta_{industry}$ and γ_t are country-fixed effects, industry-fixed effects, and year/month-fixed effects, respectively. α_1, our coefficient of interest, is the carbon risk premium, as it represents the marginal impact of $Emissions$ on stock returns.

2. Full Sample

We first analyze the carbon risk premium by estimating Equation (1) using our full sample of 1,177 firms in 49 countries from 2016 to 2022. Table 4 reports the estimation results. Columns (1) and (2) report the estimates using the natural log scale of total GHG emissions and GHG emission intensity, respectively, as the key independent variables. In Column (1), we find a negative relationship between GHG levels and stock returns, indicating an absence of carbon risk premium in GHG levels. However, in Column (2), we find a positive and statistically significant relationship between GHG emission intensities and stock returns. Specifically, a 1% increase in the level of emission intensity corresponds to a 14-bps increase in monthly stock returns, or a 1.7% increase in annualized returns.

The existence of a carbon risk premium on GHG emission intensities instead of GHG levels contrasts to the findings in Bolton and Kacperczyk (2023). However, given that their sample covers almost all listed firms worldwide, our results complement their findings by suggesting that, investors might have shifted their focus towards carbon efficiency, as proxied by GHG emission intensity, rather than just the level of emissions, among the most climate-conscious firms in the globe. This is consistent with Aswani, Raghunandan, and Rajgopal (2023) and Zhang (2024) that GHG emission intensity can be more informative for cross-firm comparisons. Furthermore, Hartzmark and Shue (2023) also document that investors almost exclusively focus on carbon intensity when discussing net zero investment strategies. As such, not surprisingly, the role of GHG emission intensity in pricing carbon risk could be crucial. While Bolton and Kacperczyk (2023) analyzed data from 2005 to 2018 and our sample spans from 2016 to 2022, Appendix B demonstrates that even when extending the sample to cover 2005 to 2022, the carbon risk premium persists only for GHG emission intensities among the most climate-conscious firms globally. This further confirms that investors' focus may differ between large and small firms.

[TABLE 4 HERE]

3. Regional Breakdown

Next, we compare the results for our regression models across three geographic regions: North America, Europe, and Others. We classify a firm's region based on the location. Since our analysis found that carbon risk premium exists only for emission intensities in our sample, we will focus on reporting the results with emission intensities going forward. Given that North America and Europe are relatively well-developed, firms in these two regions are expected to bear more climate responsibility. As such, the carbon risk premium in these two regions should differ from that in Others.

Table 5 reports the estimation results. As expected, carbon risk premium is significantly positive for firms in North America and Europe, whereas carbon risk premium is statistically insignificant for firms in Others. While the numerical results differ somewhat from those in Aswani, Raghunandan, and Rajgopal (2024) – which showed that carbon risk premium is mostly insignificant in the US and sometimes insignificant in Europe - our findings are still largely in line with their work. Specifically, we find that carbon risk premium is larger in Europe than in the US, suggesting that investors of European firms may care more about carbon efficiency than do those of US firms. In addition, given that Aswani, Raghunandan, and Rajgopal (2024) cover the periods before 2020, our results complement their findings and suggest that investors have started to focus more on carbon efficiency.

[TABLE 5 HERE]

Having shown the existence of carbon risk premium, especially among firms in North America and Europe, we now explore the impact of firms' NZC on the size of this premium.

B. Net Zero Commitment

A firm's NZC implies that it has pledged to take action to curb its GHG emissions before certain deadlines. In the theoretical framework, Propositions (2) and (3) showed that a firms'

NZC could alter the size of its carbon risk premium either positively or negatively. In this subsection, we systematically evaluate the impact of NZC declaration and relevant mediating factors.

1. Empirical Specification

Defining the dummy variable $D_{i,t}^{NZ}$ equal to 1 when firm i has declared its NZC by time t and equal to 0 otherwise. We can evaluate the impact of NZC on the carbon risk premium by augmenting Equation (1) as follows:

$$(2) \qquad RET_{i,t} = \alpha_0 + \alpha_1 Emissions_{i,t-1} + \alpha_2 D_{i,t-1}^{NZ} + \alpha_3 Emissions_{i,t-1} \times D_{i,t-1}^{NZ} + \alpha_4 Controls_{i,t-1} + \mu_{country} + \delta_{industry} + \gamma_t + \varepsilon_{i,t}.$$

Under this specification, the marginal impact of $Emissions$ on stock returns is given by $\alpha_1 + \alpha_3 D_{i,t-1}^{NZ}$. As such, the additional impact on carbon risk premium from a firm's NZC can be attributed to α_3. If α_3 is positive (negative), then NZC results in a larger (smaller) carbon risk premium. Meanwhile, the marginal impact of NZC on stock returns is given by $\alpha_2 + \alpha_3 Emissions_{i,t-1}$.

2. Full Sample

We begin the analysis of the impact of a firm's NZC on its carbon risk premium by estimating Equation (2) using our full sample. Table 6 reports the estimation results. We find that, on average, a firm's NZC has no statistically significant impact on its carbon risk premium, as the coefficient of *LOG GHG intensity* × D^{NZ} is not significantly different from zero. In addition, NZC itself has no additional impact on stock returns.

[TABLE 6 HERE]

However, the statistically insignificant impact of NZC is unsurprising given our theoretical framework, which suggests that NZC can affect carbon risk premium in both directions. As suggested in the introduction, the size of the carbon risk premium depends on investors' perception on the carbon risk exposure. Whether the carbon risk premium increases after a firm's NZC thus depends on investors' perception of whether net zero is optimal to the firm. If investors believe that the firm declaring NZC has sufficiently high transition readiness and can decarbonize smoothly, a stronger transition ambition could be compatible with long-run profit maximization, leading to a drop in the carbon risk premium. Conversely, if investors perceive that the firm declaring NZC does not possess adequate technologies to actualize its transition ambition, NZC may signal the incurrence of prohibitive abatement costs, leading to a rise in carbon risk premium. Thus, we segment the sample data to investigate the determinants of the sign of α_3 and the total impact of NZC on stock returns.

3. Transition Capacity

Transition capacity refers to the ability of a firm to decarbonize its value chain. For firms with lower transition capacity, such as those with insufficient low-carbon transition technology, abating GHG emissions will incur prohibitively high costs, which may not be optimal from the perspective of the firm's long-run profit maximization. Once those firms declare their NZC, their carbon risk premium is expected to increase, as investors perceive that they would fail to actualize their transition ambition.

To empirically test this hypothesis, we first divide the sample into two groups. The first group consists of firms from the full sample that are in countries with a lower-than-median energy use per capita. The second group consists of firms from the full sample that are in countries with a higher-than-median energy use per capita. Energy use per capita is a proxy for firms' transition capacity. A lower energy consumption per capita suggests that the country has a higher energy efficiency which allows it to edge closer to achieving a low-emission economy and indicates a declining future demand for fossil fuels. Both reflect a more advanced level of decarbonization technology compared to countries with higher energy consumption. As a result, firms in countries with lower energy consumption per capita can benefit from increased transition capacities through technology spillover within their country.[12] Therefore, we expect that the change in the carbon risk premium of firms in countries with higher-than-median energy use per capita will be more positive after their declarations of NZC, compared to firms in countries with lower-than-median energy use per capita.

We estimate Equation (2) for the two subsamples. Table 7 reports the estimation results. Column (1) corresponds to firms in countries with a lower-than-median energy use per capita in the full sample, while Column (2) corresponds to firms in countries with a higher-than-

[12] Ideally, a firm's transition capacity should be measured by firm-level's reliance on energy. However, such information is yet to be available. As such, we adopt the country-level's energy consumption per capita as the proxy, this proxy is also used by Bolton and Kacperczyk (2023) to measure firms' technological level in energy mix.

median energy use per capita in the full sample. We note that in both Column (1) and Column (2), there are no significant carbon risk premia before the firm's NZC declaration. Column (1) further indicates that carbon risk premium decreases insignificantly after firms declare NZC. In contrast, Column (2) shows that the carbon risk premium increased by 13-bps following NZC declaration, suggesting that investors perceive that these firm would fail to actualize their transition ambition.

[TABLE 7 HERE]

The analysis suggests that, using the consumption-side measure of transition capacity, investors perceive NZC as increasing the carbon risk for firms in countries with higher energy use per capita. Next, we empirically explore how the production-side measure of transition capacity impacts the size of NZC declarations on carbon risk premium.

The sample is divided into two groups. The first group consists of firms in countries with a higher-than-median share of renewable electricity output in the full sample, whereas the second group consists of firms in countries with a lower-than-median share of renewable electricity output in the full sample. The share of renewable electricity output serves as a proxy for the transition capacity. A higher share indicates that a country has developed a more robust technological knowledge base in renewable energy production, which is instrumental for achieving low-carbon transition. As such, firms located in countries with higher share of renewable electricity output can benefit from enhanced transition capacities through knowledge and technology spillovers within their countries. Therefore, we expect that compared to firms in countries with a higher-than-median share of renewable electricity output, the change in the carbon risk premium of firms in countries with a lower-than-median share of renewable electricity output is more positive after their NZC declaration.

We estimate Equation (2) for the two subsamples. Table 7 reports the estimation results. Column (3) corresponds to firms in countries with a higher-than-median share of renewable electricity output in the full sample; Column (4) corresponds to firms in countries with a lower-than-median share of renewable electricity output in the full sample. We note that Column (3) reflects no significant carbon risk premia before the firm declared its NZC, and the carbon risk premium decreases by 13-bps after the declaration. In contrast, Column (4) reflects significantly positive carbon risk premia before the NZC declaration, and the carbon risk premium further increases by 17-bps after such a declaration.

These results, using both the consumption-side and production-side measures of transition capacity, suggest that investors perceive attaining net zero is suboptimal (optimal) for firms with lower (higher) transition capacity. Regarding the impact on stock returns, both Column (1) and Column (3) show that the commitment reduces stock returns via a reduction in the carbon risk premium., indicating that the decrease in the stock returns is more significant for firms with higher GHG emission intensity after their NZC declaration. In contrast, Column (2) shows that NZC declaration increases stock returns via carbon risk premium, Column (4) shows that the impact of a NZC declaration on stock returns equals $-0.78 + 0.17 \times LOG\ GHG\ intensity$, implying that stock returns decrease when $LOG\ GHG\ intensity$ is less than 4.579 but increases when $LOG\ GHG\ intensity$ is greater than 4.579.[13]

The latter result suggests that even if firms have low transition capacity, it is still possible that the low-emitters could obtain a higher enterprise value after declaring NZC. This could be due to the relatively low abatement cost associated with their low GHG emission intensity, or increased investor demand for stocks of such firms following their NZC declaration. However, a NZC declaration may eventually hurt the total enterprise value once the firm's GHG emission intensity exceeds a certain threshold.

4. Transition Urgency

Transition urgency refers to the degree of immediacy with which a firm must act to transition to a low-carbon business model. Firms in countries with loose climate policies may face weak transition urgency, as the marginal cost of emitting GHG emissions is negligible, and achieving net zero may not be optimal for them due to the unnecessary abatement costs. In contrast, firms in countries with more ambitious climate policies, such as those that have extensive coverage of carbon prices, face strong transition urgency. For these firms, achieving net zero could be optimal as it may reduce their exposure to potential policy risk associated with their stock of GHG emissions. In the latter case, the carbon risk premium is expected to decrease following the NZC declaration, as investors may perceive the transition ambition as a positive signal.

To empirically test this hypothesis, we divide the sample into two groups. The first group consisting of firms in countries with a lower-than-median policy-driven trend in CO_2 emissions intensity in the full sample, whereas the second group consists of firms in countries with a higher-than-median policy-driven trend in CO_2 emissions intensity in the full sample. The policy-driven trend in CO_2 emissions intensity, sourced from the Environmental

[13] In this subsample, 66% of the observations have a $LOG\ GHG\ intensity$ value larger than 4.579.

Performance Index constructed by the Yale Center for Environmental Law & Policy (Wolf et al., 2022), captures whether countries' government climate policy is stringent to reach zero emissions. A score is generated that represents the country's performance. A country with lower growth in the policy-driven trend receives a higher score, indicating a more stringent climate policy implemented to curb CO_2 intensity in that country. Under this set-up, firms in countries with a higher score face a stronger transition urgency. We expect that the change in the carbon risk premium of firms in countries with a higher-than-median score will be more negative than that of firms in countries with a lower-than-median score after their NZC declaration.

We estimate Equation (2) for the two subsamples. Table 8 reports the estimation results. Column (1) corresponds to firms in countries with a higher-than-median score of policy-driven trend in CO_2 emissions intensity in the full sample; Column (2) corresponds to firms in countries with a lower-than-median score of policy-driven trend in CO_2 emissions intensity in the full sample. We note that in Column (1), there were already significantly positive carbon risk premia before the NZC declaration, but this premium decreased by 18-bps after the declaration, suggesting that investors perceive such declaration as a positive signal. In contrast, in Column (2), although there were insignificant carbon risk premia before firms declared NZC, the carbon risk premium increased by 12-bps after such declaration.

Regarding the impact of stock returns, Column (1) shows that such a commitment impacts stock returns by $0.98 - 0.18 \times LOG\ GHG\ intensity$. That's said, a NZC is associated with higher stock returns for observations with $LOG\ GHG\ intensity$ below 5.444, and lower stock returns with $LOG\ GHG\ intensity$ above 5.444.[14] This result shows that even if firms face a strong transition urgency, the marginal benefit from abating GHG emissions for low-emitters may be too small compared to the additional cost incurred in attaining net zero. In contrast, Column (2) indicates that the marginal impact of a NZC on stock returns equals to $0.12 \times LOG\ GHG\ intensity$, showing that higher stock returns are associated with greater GHG emission intensity after NZC.

[TABLE 8 HERE]

The analysis above shows that investors perceive NZC declaration as increasing (decreasing) the carbon risk for firms in countries with greater (lower) growth in policy-driven

[14] In this subsample, 38% of the observations have a $LOG\ GHG\ intensity$ value larger than 5.444.

CO_2 emissions intensity. As mentioned earlier, the government may also introduce carbon pricing during the transition to carbon neutrality. By pricing carbon, firms face higher costs for GHG emissions. Firms in countries with a positive carbon price face stronger transition urgency than are those without a carbon price. However, carbon prices were not imposed on all economic sectors in the country. Intuitively, countries with more ambitious carbon neutrality goals would cover a wider range of economic sectors with the carbon price, implying stronger transition urgency for firms in those countries.[15]

To empirically test this hypothesis, we divide the sample into two groups. The first group consists of firms in countries with a higher-than-median share of CO_2 emissions covered by a carbon price in the full sample, whereas the second group consists of firms located at countries with a lower-than-median share of CO_2 emissions covered by a carbon price in the full sample.

We estimate Equation (2) for the two subsamples. Table 8 reports the estimation results. Column (3) corresponds to firms in countries with higher-than-median shares of GHG emissions covered by a carbon price in the full sample; Column (4) corresponds to firms in countries with lower-than-median shares of GHG emissions covered by a carbon price in the full sample. Column (3) suggests that NZC only brings statistically insignificant reduction in carbon risk premium. In contrast, Column (4) shows carbon risk premium increase by 15-bps after the NZC declaration.

Regarding stock returns, Column (3) shows that such a commitment has a negligible impact on the stock returns. However, Column (4) indicates that the marginal impact of a NZC on stock returns equals $-0.75 + 0.15 \times LOG\ GHG\ intensity$, indicating that a firm's declaration of NZC is associated with lower stock returns if $LOG\ GHG\ intensity$ is below 5 whereas such a declaration is associated with higher stock returns if $LOG\ GHG\ intensity$ is above 5.[16] The latter result further indicates that for high-emitting firms with weak transition urgency, declaring a NZC could lower their total enterprise value. Overall, the analysis shows that investors perceive attaining net zero as suboptimal (optimal) for firms with weaker (stronger) transition urgency. Thus, a NZC declaration will be considered as a bad (good) signal.

5. *Investors' Discount Rate*

[15] Carbon price mainly takes two forms: carbon taxes, where a price is set for each unit of CO_2 emitted, and cap-and-trade, which limits the total amount of CO_2 that can be emitted by firms by forcing firms to purchase emissions rights if they exceed a given emissions allowance.

[16] In this subsample, 49% of the observations have a value $LOG\ GHG\ intensity$ smaller than 5.

Investors with longer time horizons typically have lower discount rates compared to those with shorter time horizons (Thaler, 1981; Frederick, Loewenstein, and O'Donoghue, 2002). The existing literature suggests that firms with stronger environmental performance can attract investors with a longer-term investment horizon (for example, Starks, Venkat, and Zhu, 2017; Pastor, and Vorsatz, 2020; Garel, and Petit-Romec, 2021). Many investment managers implement their ESG investment strategies using ESG scores and sub-scores (Elmalt, Igan, and Kirti, 2021). These longer-term investors place a higher value on the long-term benefits of achieving net zero. In other words, firms with higher environmental pillar score tend to attract investors with lower discount rates. As such, we divide the sample into two groups. The first group consists of firms with a higher-than-median environmental pillar score in the full sample, whereas the second group consists of firms with a lower-than-median environmental pillar score in the full sample. Under this specification, the first group is more likely to attract long-term investors, and hence we expect NZC in the first group to be perceived as more favorably by investors.

We estimate Equation (2) for the two subsamples. Table 9 reports the estimation results. Column (1) corresponds to observations with an above-the-median environmental pillar score in the full sample; Column (2) corresponds to observations with a below-the-median environmental pillar score in the full sample. We note that in Column (1), there is a significant positive carbon risk premium of 45-bps before NZC declaration, and the carbon risk premium decreased by 14-bps after NZC declaration, which suggests a favorable reception of transition ambition. In contrast, in Column (2), we found no significant carbon risk premium before NZC declaration, which might suggest that investors investing in firms with lower environmental pillar scores might not consider the carbon risk factor important. In the same vein, the carbon risk premium increased by 15-bps after NZC declaration, which suggests an unfavorable reception of transition ambition.

[TABLE 9 HERE]

Investors' discount rates could also be affected by firm's short-termism. Again we divide the sample into two groups, the first group consists of firms without golden parachute in the full sample, whereas the second group consists of firms with golden parachute in the full sample. Firms with golden parachutes provide additional job security for executives, which encourages them to prioritize short-term performance over long-term sustainability (Shive and

Forster, 2020). Such short-termism may deter long-term investors, and hence we expect NZC in the second group to be perceived as more unfavorable by their investor base.

We estimate Equation (2) for the two subsamples. Table 9 reports the estimation results. Column (3) corresponds to observations without golden parachute in the full sample; Column (4) corresponds to observations with golden parachute in the full sample. We note that in Column (3), there is no significant carbon risk premium before the firm declared its NZC. The carbon risk premium insignificantly decreased after such declarations. In contrast, in Column (4), although we found no significant carbon risk premium before the firms declared their NZC, the carbon risk premium increased by 16-bps after such declarations. This finding verifies that shorter-term investors regard attaining net zero as suboptimal to the firm's profit maximization objective, thus demanding a larger carbon risk premium.

Taken together, these findings suggest that a declaration of NZC is a double-edged sword. The direction and magnitude of the impact hinge on the firm's transition readiness, which increase with its transition capacity and transition urgency, and decrease with discount rates placed by investors on the firm. These findings not only verify that the impact of NZC to firm's values extends beyond the creditability of NZC, but they also yield crucial implications for both firms and policymakers. Firms should ensure they have sufficient transition readiness before declaring NZC. Otherwise, they may face a higher cost of equity due to increased carbon risk premium, which would be detrimental to their corporate finance decisions.

For policymakers, it is essential to ensure that firms declaring NZC have a sufficient degree of transition readiness. Otherwise, the carbon risk premium in the financial market could accumulate rapidly, leading to the abrupt repricing and stronger co-movement of asset prices, which threaten financial market stability. Besides, given the importance of achieving net zero, governments should not only encourage firms to pursue low-carbon transitions but also implement policies to enhance their transition readiness. This could include promoting international cooperation on low-carbon technology development and subsidizing green innovation could also be considered which aim to strengthen transition capacity. For increasing transition urgency, the government could increase public awareness and education about climate change. Besides, designing a more transparent and clearer roadmap for achieving low-carbon emissions would be beneficial. Finally, promoting financial innovation to expand the range of long-term investor bases could be beneficial, as this may help lower the discount rates in the market. By fostering these initiatives, firms can benefit from a lower cost of equity, incentivizing them to declare their NZC.

C. Divestment from Institutional Investors

As shown in Bolton and Kacperczyk (2021), the existence of a carbon risk premium could result from institutional investors' divestment from stocks of companies with high emissions. In this subsection, we similarly explore whether the change in the carbon risk premium could be attributed to the divestment behaviour of institutional investors. We first study whether institutional investors reduce holdings on firms with high emissions, then explore the asset pricing implication on firm's NZC.

1. Empirical Specification

To test whether institutional investors divest more from high emitting firms after their NZC, we estimate the following regression model:

$$(3) \quad IO_{i,t} = d_0 + d_1 Emissions_{i,t-1} + d_2 D^{NZ}_{i,t-1} + d_3 Emissions_{i,t-1} \times D^{NZ}_{i,t-1} + d_4 Controls_{i,t-1} + \mu_{country} + \delta_{industry} + \gamma_t + \varepsilon_{i,t}.$$

The dependent variable $IO_{i,t}$ measures the percentage of the shares of firm i owned by institutional investors in month t. Under this specification, the marginal impact of $Emissions$ on institutional holding is given by $d_1 + d_3 D^{NZ}_{i,t-1}$. Therefore, the sign of d_3 addresses whether institutional investors treat NZC differently based on a firm's emissions.

2. Institutional Investor Holdings

We report the estimation results in Table 10. Column (1) shows that the association between institutional ownership and GHG emissions is insignificantly negative while Column (3) shows that a 1% increase in GHG emission intensity significantly lowers institutional ownership by 1.51 percentage points. These findings are consistent with Bolton and Kacperczyk (2021), suggesting that institutional investors hold a smaller fraction of companies with high emission intensity, but not necessarily under-weigh companies with higher levels of emissions.

We analyze the impact of NZC on institutional ownership in Column (2) and (4). Column (2) shows that after NZC, the marginal reduction in institutional ownership due to a 1% increase in GHG emissions equals 0.42 percentage point, suggesting that institutional investors reduce holding of firms with high levels of GHG emissions after their NZC declaration. In addition, Column (4) shows that the marginal reduction in GHG emission intensity on institutional ownership increases by 0.35 percentage point after the firm declares its NZC, suggesting that institutional investors not only tend to reduce the holdings of firms with high emission intensity but also divest more aggressively after the NZC declaration of these firms.

Alternatively, we could interpret the results as showing that NZC does not necessarily result in greater institutional ownership. Column (2) shows that the marginal impact of NZC on institutional ownership equals $7.20 - 0.42 LOG\ GHG$ while Column (4) shows that the marginal impact of NZC on institutional ownership equals $2.76 - 0.35 LOG\ GHG\ Intensity$. This means that NZC may result in lower institutional ownership for firms with $LOG\ GHG$ above 17.14 (in Column (2)) or $LOG\ CO2\ Intensity$ above 7.89 (in Column (4)). These results further verify that NZC by high-emitters could result in divestment by institutional investors.

The additional divestment from institutional investors due to NZC is not surprising. While maximizing (risk-adjusted) monetary returns remains the primary objective for typical investors, they tend to prefer a lower carbon footprint in their portfolios. This leads them to disfavor firms with high GHG emissions while in favor firms with NZC. However, since abatement costs are positively associated with the inventory of GHG emissions, a NZC signals to investors that these costs will begin to materialize. Consequently, portfolio returns are likely to decline for high-emitting firms that have declared NZC, given the expectation of significant abatement costs. As a result, such commitments may deter investors from holding stocks in these high-emitting firms.

[TABLE 10 HERE]

As shown in Bolton and Kacperczyk (2021), institutional investors appear to implement exclusionary screening only in a few salient high-emission industries in the US sample. In other words, only the most salient high-CO_2 industries are excluded from the portfolios of institutional investors. To further investigate this, following Bolton and Kacperczyk (2021), we re-estimate Equation (3) again after excluding the high-emitting industries, namely, Energy, Transportation and Utilities, in order to examine whether the divestment behavior still exist against firms in other industries.

We report the estimation results in Table 11. Column (1) and (3) show that after excluding the salient high-emitting industries, institutional investors still hold fewer shares in high-emitting firms, indicating that the negative screening of these large firms has not been limited to just the selected high-emitting industries. Interestingly, the coefficient of $Emissions$

in Column (1) turns out to be significantly negative, indicating that institutional investors tend to divest from high-emitting firms beyond those in the high-emitting industries.

Moreover, the marginal impact of NZC on institutional ownership remains unchanged. Column (2) and (4) demonstrate that institutional investors divest even more aggressively from high-emitting firms after their NZC declaration.

[TABLE 11 HERE]

3. Impact on Carbon Risk Premium

We then explore whether a reduction in institutional holdings could impact the size of the carbon risk premium. Similar to the preceding analysis, we divide the sample by observations into four groups based on the quartiles of institutional ownership. We then estimate Equation (2) with these four subsamples.

Table 12 presents the estimation results. Columns (1), (2), (3) and (4) correspond to observations with first, second, third and fourth quartiles of institutional ownership, respectively. In other words, compared to retail investors, the relative importance of institutional investors is increasing from Column (1) to Column (4). We note that in Columns (1) and (2), for observations with a smaller share of institutional investment, the carbon risk premium is insignificant both before and after their NZC declaration. However, as the participation of institutional investors increases, the carbon risk premium starts to manifest. Column (3) shows that the carbon risk premium increased by 18-bps after NZC declaration. The impact becomes even more significant in Column (4), which represents the subsample with the highest institutional ownership. Before NZC declaration, there was already a 33-bps of carbon risk premium; after NZC declaration, the latter further increased by 23-bps.

Furthermore, Columns (1) and (2) show that NZC has no impact on stock returns when institutional investors' participation is relatively low. In contrast, Column (3) indicates that NZC is associated with higher stock returns when $LOG\ GHG\ intensity$ is above 5.333,[17] whereas Column (4) indicates that NZC is associated with higher stock returns even when $LOG\ GHG\ intensity$ is only above 4.913.[18]

[TABLE 12 HERE]

[17] In this subsample, 48% of observations have a $LOG\ GHG\ intensity$ value larger than 5.333.
[18] In this subsample, 50% of observations have a $LOG\ GHG\ intensity$ value larger than 4.913.

The combined results highlight the pivotal role of institutional investors in channeling carbon risk into stock returns. Institutional investors not only tend to divest from stocks with high emission intensity but they also price in a larger risk premium for such high-emitting firms. In addition, institutional investors play a crucial role in penalizing NZC declaration by high emitters. These findings carry important implications for firms' decisions to declare NZC. The result suggests that following NZC declaration, funds from institutional investors may be withheld if the firm has relatively high levels of emission intensity, which might eventually introduce additional volatility toward the wealth of shareholders.

VI. Conclusion

Achieving net zero is the only way to avoid any irreversible impact of climate change. Coordinated actions around the globe are necessary to reach this goal. As investors ramp up pressure on firms to prioritize climate initiatives, an increasing number of firms have also pledged to attain net zero. However, uncertainty remains about whether firms could actualize their promises in a smooth and cost-efficient manner, which has significant financial implications for investors.

This paper studies how the interaction of carbon risks and NZC is reflected in stock returns using both theoretical modelling and empirical estimation. Theoretically, we demonstrate that the effect of NZC on the enterprise value, and hence the carbon risk premium, depends on the financial materiality of carbon risks. Investors' behavior can be rationalized through an intertemporal cost-benefit analysis. Compared to existing studies that explain the lower expected returns of green assets through green preference, our theory offers an alternative explanation which captures a more diverse set of asset pricing phenomena.

Empirically, we undertake a cross-sectional returns analysis with a sample of over 1,100 publicly listed firms across 49 countries that had declared a net zero commitment by the end-December 2022. We find that among these globally systemically important firms, there is a positive carbon risk premium in a firm's emission intensity, i.e., stock returns increase with firm's emission intensity. Although this carbon risk premium, on average, is not affected by a firm's NZC declaration, the relationship between the carbon risk premium and such a declaration is influenced by the firm's transition capacity, transition urgency and investor discount rates. These findings underscore the importance of regulatory supervision of firms that have declared NZC, as the accelerated accumulation of carbon risk premia in the equity market could result in substantial equity market volatility.

We also identify the importance of institutional investors in channeling carbon risk into stock returns. Institutional investors tend to divest from stocks with high emission intensity and price in a larger premium for such firms. The impact is amplified after a firm's NZC declaration and for firms with more concentrated institutional ownership. Given the importance of positive institutional investors flows for fostering financial market growth, and variability in these flows can lead to financial instability, manifesting as volatile asset prices and fluctuations in the costs of capital. Our findings carry important policy implications for jurisdictions seeking to expand and maintain stability of their institutional investor base.

Finally, we would like to highlight a few avenues for future research to better understand the impact of NZC on financial markets. First, additional proxies of firms' transition readiness, including firms' social and governance scores, could be explored given that the concept is relatively new. Second, we treat different firms' NZC declarations as homogenous. However, even firms that strive to attain net zero by the same deadline may have very different transition pathways, and hence different transition ambition. The latter could affect whether a firm has sufficient transition readiness to measure up, and hence whether NZC is perceived favorably. Third, as different types of institutional investors might have different investment horizons and environmental consciousness, a more granular breakdown of the type of institutional investors could enhance our understanding of their role in channeling carbon risk to asset pricing. Finally, considering the evolution of the sustainable finance market and finance literature, traditional methods of estimating expected returns based on realized returns and transition risk using backward-looking metrics may not always be appropriate. Adopting more nuanced methodologies and forward-looking measures of climate risk metrics might also be beneficial. We leave them for future research.

References

Alessi, L., Ossola, E., & Panzica, R., 2021. What greenium matters in the stock market? The role of greenhouse gas emissions on environmental disclosures. *Journal of Financial Stability*, 54, 100869.

Ardia, D., Bluteau, K., Boudt, K., & Inghelbrecht, K., 2022. Climate change concerns and the performance of green vs. brown stocks. *Management Science,* 69(12), pp. 7607-7632.

Aswani, J., Raghunandan, A., & Rajgopal, S., 2024. Are carbon emissions associated with stock returns? *Review of Finance,* 28(1), pp. 75-106.

Avramov, D., Cheng, S., Lioui, A., & Tarelli, A., 2022. Sustainable investing with ESG rating uncertainty. *Journal of Financial Economics,* 145, pp. 642-664.

Baldauf, M., Garlappi, L., & Yannelis, C., 2020. Does climate change affect real estate prices? Only if you believe in it. *The Review of Financial Studies*, 33(3), pp. 1256-1295.

Bansal, R., Kiku, D., & Ochoa, M., 2019. Climate change risk. *Unpublished Working Paper,* Retrieved from https://www.frbsf.org/wp-content/uploads/sites/4/Paper-5-2019-11-8-Kiku-1PM-1st-paper.pdf

Bernstein, A., Gustafson, M. T., & Lewis, R., 2019. Disaster on the horizon: The price effect of sea level rise. *Journal of Financial Economics*, 134(2), pp. 253-272.

Bolton, P., & Kacperczyk, M., 2021. Do investors care about carbon risk? *Journal of Financial Economics*, 142, pp. 517-549.

Bolton, P., & Kacperczyk, M., 2023. Global pricing of carbon-transition risk. *The Journal of Finance*, 78(6), pp. 3677-3754.

Bolton, P., & Kacperczyk, M., 2024. Firm commitments. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3840813

Brandon, R. G., Glossner, S., Krueger, P., Matos, P., & Steffen, T., 2022. Do responsible investors invest responsibly? *Review of Finance*, 26(6), pp. 1389-1432.

Cao, J., Titman, S., Zhan, X., & Zhang, W., 2022. ESG preference, institutional trading, and stock return patterns. *Journal of Financial and Quantitative Analysis,* 58(5), pp. 1843-1877.

Cenedese, G., Han, Shangqi, & Kacperczyk, M., 2024. Carbon-transition risk and net zero portfolios. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4565220

Chan, K. J. D., Cheung, B., & Shen, L. Y., 2024. An economic foundation for assessing the credibility of corporate net zero transition pathways. *Business Strategy and the Environment*, 1–14.

Chan, K. J. D., & Wan, W, T. S., 2024. Does carbon pricing induce firms to understate their emissions? An international assessment on emissions disclosure accuracy. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4400771

Chava, S., 2014. Environmental externalities and cost of capital. *Management Science,* 60(9), pp. 2223-2247.

Choi, D., Gao, Z., & Jiang, W. (2020). Attention to global warming. *The Review of Financial Studies*, 33(3), pp. 1112-1145.

Choi, D., Gao, Z., Jiang, W., & Zhang, H. (2021). Global carbon divestment and firms' actions. *Unpublished Working Paper,* Retrieved from https://www.wiwi.huberlin.de/en/Professorships/bwl/finance/seminars/papers-fin-acc-res-seminars/21ws/choi.pdf

Cohen, S., Kadach, I., & Ormazabal, G., 2023. Institutional investors, climate disclosure, and carbon emissions. *Journal of Accounting and Economics,* 76(2-3), 101640.

Dai, R., Duan, R., Liang, H., & Ng, L., 2024. Outsourcing climate change. *ECGI Working Paper Series in Finance,* #723/2021.

De Angelis, T., Tankov, P., & Zerbib, O. D., 2022. Climate impact investing. *Management Science,* 69(12), pp. 7669-7692.

Delis, M. D., De Greiff, K., Iosifidi, M., & Ongena, S., 2024. Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans. *Financial Markets, Institutions & Instruments,* pp. 1-27.

Duan, T., Li, F. W., & Wen, Q., 2023. Is carbon risk priced in the cross section of corporate bond returns? *Journal of Financial and Quantitative Analysis,* First View, pp. 1-35.

Dyck, A., Lins, K. V., Roth, L., & Wagner, H. F., 2019. Do institutional investors drive corporate social responsibility? International evidence. *Journal of Financial Economics,* 131(3), pp. 693-714.

Edenhofer, O., Lessmann, K., & Tahri, I., 2024. Asset pricing and the carbon beta of externalities. *Journal of Environmental Economics and Management,* 125, 102969.

Ehlers, T., Packer, F., & De Greiff, K., 2022. The pricing of carbon risk in syndicated loans: Which risks are priced and why? *Journal of Banking and Finance,* 136, 106180.

El Ghoul, S., Guedhami, O., Kwok, C. C. Y., & Mishra, D. R., 2011. Does corporate social responsibility affect the cost of capital? *Journal of Banking and Finance,* 35(9), pp. 2388-2406.

Elmalt, D., Igan, D., & Kirti, D., 2021. Limits to private climate change mitigation. *IMF Working Paper,* #112.

Engle, R. F., Giglio, S., Kelly, B., Lee, H., & Stroebel, J., 2020. Hedging climate change news. *The Review of Financial Studies,* 33(3), pp. 1184-1216.

Faccini, R., Matin, R., & Skiadopoulos, G., 2023. Dissecting climate risk: Are they reflected in stock prices? *Journal of Banking and Finance,* 155, 106948.

Frederick, S., Loewenstein, G., & O'Donoghue, T., 2002. Time discounting and time preference: A critical review. *Journal of Economic Literature,* 40(2), pp. 351-401.

Fortune, 2021. Corporate greenwashing is all the rage. How can we stop it? April, 2021.

Garel, A., & Petit-Romec, A., 2021. Investor rewards to environmental responsibility: Evidence from the COVID-19 crisis. *Journal of Corporate Finance,* 68, 101948.

Giglio, S., Maggiori, M., Rao, K., Stroebel, J., & Weber, A., 2021. Climate change and long-run discount rates: Evidence from real estate. *The Review of Financial Studies,* 34(8), pp. 3527-3571.

Goldsmith-Pinkham, P., Gustafson, M. T., Lewis, R. C., & Schwert, M., 2023. Sea-level rise exposure and municipal bond yields. *The Review of Financial Studies,* 36(11), pp. 4588-4635.

Gorgen, M., Jacob, A., Nerlinger, M., Riordan, R., Rohleder, M., & Wilkens, M., 2020. Carbon risk. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2930897

Hartzmark, S. M., & Shue, K., 2023. Counterproductive sustainable investing: The impact elasticity of brown and green firms. *Unpublished Working Paper,* Retrieved from https://www.icpmnetwork.com/wp-content/uploads/2023/07/Counterproductive-Sustainable-Investing-the-Impact-Elasticity-of-Brown-and-Green-Firms.pdf

Hartzmark, S. M., & Sussman, A. B., 2019. Do investors value sustainability? A natural experiment examining ranking and fund flows. *The Journal of Finance*, 74, pp. 2789-2837.

Heinkel, R., Kraus, A., & Zechner, K., 2001. The effect of green investment on corporate behavior. *Journal of Financial and Quantitative Analysis,* 36, pp. 431-450.

Ho, K., & Wong, A., 2023. Effect of climate-related risk on the costs of bank loans: Evidence from syndicated loan markets in emerging economies. *Emerging Markets Review*, 55, 100977.

Hong, H., Wang, N., & Yang, J., 2023. Mitigating disaster risks in the age of climate change. *Econometrica,* 91(5), pp. 1763-1802

Hsu, P. H., Li, K., & Tsou, C. Y., 2023. The pollution premium. *The Journal of Finance,* 78(3), pp. 1343-1392.

Huynh, T. D., & Xia, Y., 2020. Climate change news risk and corporate bond returns. *Journal of Financial and Quantitative Analysis,* 56(6), pp. 1985-2009.

Ilhan, E., Sautner, Z., & Vilkov, G., 2021. Carbon tail risk. *The Review of Financial Studies,* 34(3), pp. 1540-1571.

Intergovernmental Panel on Climate Change., 2018. Global warming of 1.5°C. Retrieved from https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_LR.pdf

Kahn, M. E., Matsusaka, J. G., & Shu, C. Divestment and engagement: The effect of green investors on corporate carbon emissions. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4592023

Kordsachia, O., Focke, M., & Velte, P., 2022. Do sustainable institutional investors contribute to firms' environmental performance? Empirical evidence from Europe. *Review of Management Science*, 16, pp. 1409-1436.

Krueger, P., Sautner, ZZ., Starks, L., 2020. The importance of climate risks for institutional investors. *The Review of Financial Studies*, 33, pp. 1067-1111.

Leung, V., Wan, W., & Wong, J., 2023. The shade of green: Greenwashing in the corporate green bond markets. *HKIMR Working Paper*, #01/2023.

Liu, H., Wang, Y., Xue, R., Linnenluecke, M., & Cai, C. W., 2022. Green commitment and stock price crash risk. *Financial Research Letters*, 47(A), 102646.

Monasterolo, I., & de Angelis, L., 2020. Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement. *Ecological Economics*, 170, 106571.

Net Zero Climate., 2023. *What is net zero?* Retrieved from https://netzeroclimate.org/what-is-net-zero-2/

Nguyen, J. H., Truong, C., & Zhang, B., 2025. The price of carbon risk: Evidence from the Kyoto Protocol ratification. *Journal of Environmental Economics and Management*, 130, 103118.

Nofsinger, J. R., Sulaeman, J., & Varma, A., 2019. Institutional investors and corporate social responsibility. *Journal of Corporate Finance*, 58, pp. 700-725.

Oestreich, A. M., & Tsiakas, I., 2015. Carbon emissions and stock returns: Evidence from the EU Emissions Trading Scheme. *Journal of Banking and Finance*, 58, pp. 294-308.

Painter, M., 2020. An inconvenient cost: The effects of climate change on municipal bonds. *Journal of Financial Economics*, 135(2), pp. 468-482.

Pastor, L., & Vorsatz, M. B., 2020. Mutual fund performance and flows during the COVID-19 crisis. *The Review of Asset Pricing Studies*, 10(4), pp. 791-833.

Pastor, L., Stambaugh, R. F., & Taylor, L. A., 2021. Sustainable investing in equilibrium. *Journal of Financial Economics*, 142, pp. 450-571.

Pastor, L., Stambaugh, R. F., & Taylor, L. A., 2022. Dissecting green returns. *Journal of Financial Economics*, 146, pp. 403-424.

Pedersen, L. H., Fitzgibbons, S., & Pomorski, L., 2021. Responsible investing: The ESG-efficient frontier. *Journal of Financial Economics*, 142, pp. 572-597.

Peterson, T., 2022. Utility environmental commitments and shareholder performance. *Journal of Sustainable Finance & Investment*, DOI: 10.1080/20430795.2022.2148818

Ramelli, S., Ossola, E., & Rancan, M., 2021. Stock price effects of climate activism: Evidence from the first Global Climate Strike. *Journal of Corporate Finance*, 69, 102018.

Reshetnikova, L., Ovechkin, D., Devyatkov, A., Chernova, G., & Boldyreva, N., 2023. Carbon emissions and stock returns: The case of Russia. *Journal of Risk Financial Management*, 16(8), 370.

Safiullah, M., Alam, M. S., & Islam, M. S., 2022. Do all institutional investors care about corporate carbon emissions? *Energy Economics*, 115, 106376.

Shive, S. A., & Forster, M. M., 2020. Corporate governance and pollution externalities of public and private firms. *The Review of Financial Studies*, 33(3), pp. 1296-1330.

Starks, L. T., Venkat, P., & Zhu, Q., 2017. Corporate ESG profiles and investor horizons. *Unpublished Working Paper,* Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3049943

Sydsaeter, K., Hammond, P., Seierstad, A., & Storm, A., 2008. *Further mathematics for economic analysis,* Financial Times Prentice Hall, Retrieved from https://books.google.com.hk/books/about/Further_Mathematics_for_Economic_Analysi.html?id=mqgK08S94NAC&redir_esc=y

Thaler, R., 1981. Some empirical evidence on dynamic inconsistency. *Economics Letters,* 8(3), pp. 201-207.

Wen, F., Wu, N., & Gong, X., 2020. China's carbon emissions trading and stock returns. *Energy Economics,* 86, 104627.

Wolf, M. J., Emerson, J. W., Esty, D. C., de Sherbinin, A., Wendling, Z. A., et al., 2022. *2022 Environmental Performance Index.* New Haven, CT: Yale Center for Environmental Law & Policy. epi.yale.edu

Wong, P. Y., Ka, S., & Ng, P., 2023. The impact of climate change on Hong Kong housing prices: An initial analysis. *HKMA Research Memorandum*, 5/2023. Retrieved from https://www.hkma.gov.hk/media/eng/publication-and-research/research/research-memorandums/2023/RM05-2023.pdf

Wu, G. S. T., & Wan, W. T. S., 2023. What drives the cross-border spillover of climate transition risks? Evidence from global stock markets. *International Review of Economics & Finance*, 85, pp. 432-447.

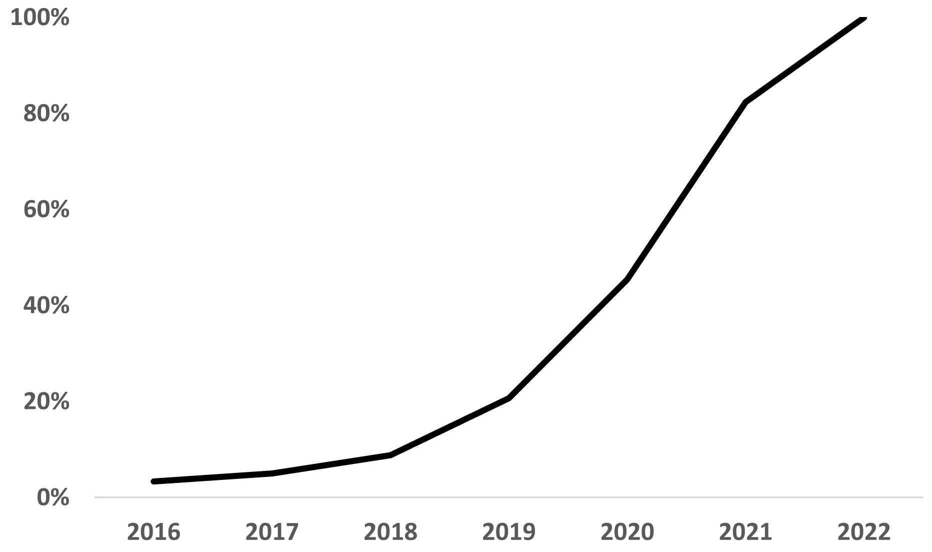
Xie, X., Lu, J., Li, M., & Dai, J., 2023. Does carbon neutrality commitment enhance firm value? *Journal of Chinese Economic and Business Studies*, 21(1), pp. 49-83.

Zhang, S., 2024. Carbon returns across the globe. *The Journal of Finance,* forthcoming.

Figures

Figure 1
Cumulative density function of declaration of net zero commitment

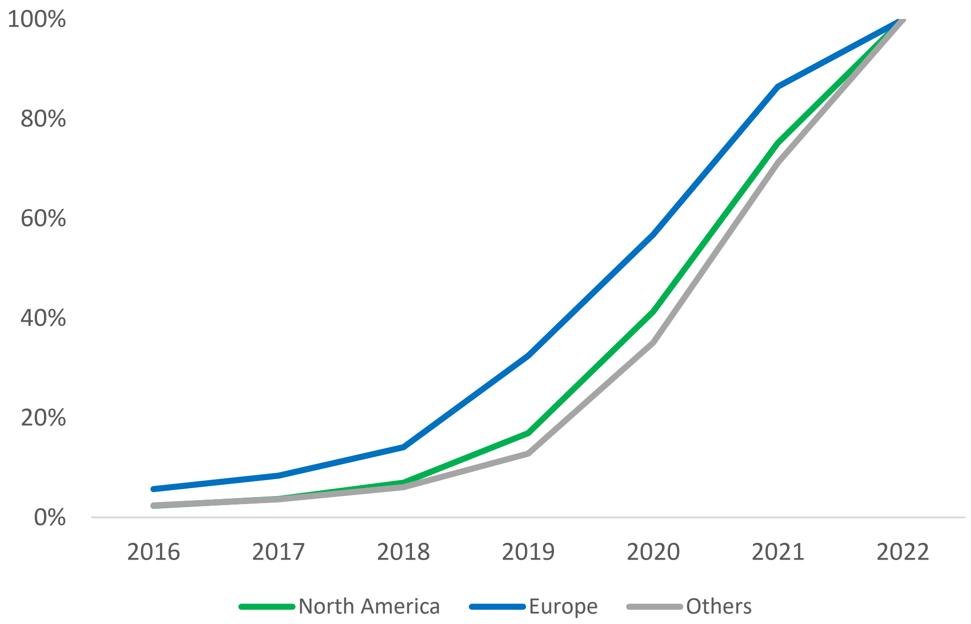
This figure presents the cumulative density function of firms in our sample declaring NZC in the period from 2016 to 2022.



Source: Authors' calculation based on information from SBTi and S&P Capital IQ Pro.

Figure 2
Cumulative density function of declaration of net zero commitment by region

This figure presents the cumulative density function of firms declaring their NZC in our sample by regional breakdown based on firm location in the period from 2016 to 2022.



Source: Authors' calculation based on information from SBTi and S&P Capital IQ Pro.

Tables

Table 1
Summary statistics

This table reports the summary statistics (averages, medians, and standard deviations) for the variables used in the regressions. The sample period is from 2016 to 2022. Panel A reports firms' environmental performance variables and declarations of NZC. $D_{i,t}^{NZ}$ is a dummy variable equal one if firm i has declared NZC at time t, and equals 0 otherwise. Panel B reports the summary statistics of the stock returns, institutional ownership, and other control variables. RET is the monthly stock return, measured by monthly log difference in stock price; IO is the percentage of shares owned by institutional investors; $LOGSIZE$ is the natural log scale of market capitalization; B/M is the book-to-market ratio; $LEVERAGE$ is the total debt to total asset ratio; MOM is the average previous 12-month stock return; $INVEST/A$ is the capital expenditure to total asset ratio; HHI is the Herfindahl index of a firm's industry with weights proportional to revenues; $LOGPPE$ is the natural log scale of property, plant and equipment; ROE is the ratio of net income to total equity; and $VOLAT$ is the standard deviation of the previous 12-month stock return. $GParachute$ is a dummy variable equal one if firm has golden parachute, and equals 0 otherwise; $ENUSEOC$ is a country's energy consumption per capita; $REOUTPUT(\%)$ is the percentage of renewable electricity output to total electricity output; CDA is the score of policy-driven trend in CO_2 emissions intensity of the country, ranging from 0 to 100, countries with lower trend in CO_2 intensity receive top scores; and $CPCOVERAGE(\%)$ is the share of CO_2 emissions covered by a carbon price.

Panel A: Firms' environmental performance and declaration of net zero commitment			
Variables	Mean	Median	Std Dev
LOG GHG	14.536	14.615	1.965
LOG Scope 1 emissions	11.864	11.656	3.019
LOG Scope 2 emissions	11.993	12.108	2.006
LOG Scope 3 emissions	13.956	14.111	1.800
LOG GHG intensity	5.159	5.077	1.358
LOG Scope 1 emission intensity	2.488	2.248	2.645
LOG Scope 2 emission intensity	2.619	2.647	1.577
LOG Scope 3 emission intensity	4.580	4.589	1.041
Environmental pillar score	57.069	57.000	22.400
$D_{i,t}^{NZ}$	0.448	0	0.497

Panel B: Stock returns, institutional ownership, and other control variables			
Variables	Mean	Median	Std Dev
RET (%)	0.768	0.657	9.055
IO (%)	69.700	70.270	26.300
$LOGSIZE$	23.646	23.603	1.185
B/M	0.711	0.636	2.538
$LEVERAGE$	0.279	0.258	0.199
MOM (%)	0.711	0.636	2.538
$INVEST/A$	0.033	0.025	0.033
HHI	2.721	1.954	3.294
$LOGPPE$	22.687	22.722	1.593
ROE	0.105	0.106	5.127
$VOLAT$	0.077	0.069	0.039
$GParachute$	0.521	1.000	0.500
$ENUSEPC$	4,753.470	4,325.524	2102.017
$REOUTPUT$ (%)	20.416	14.059	16.727
CDA	58.300	57.837	15.363
$CPCOVERAGE$ (%)	31.335	9.170	29.955

Table 2
Stock characteristics regarding declaration of net zero commitment

This table reports the sample means of the main variables from 2016 to 2022. All variables have been defined in Table 1. Column (1) represents the sub-sample of observations before declaration of NZC; Column (2) represents the sub-sample of observations after declaration of NZC.

	(1) $D_{i,t}^{NZ} = 0$	(2) $D_{i,t}^{NZ} = 1$
LOG GHG	14.484	14.621
LOG Scope 1 emissions	11.828	11.923
LOG Scope 2 emissions	11.962	12.044
LOG Scope 3 emissions	13.905	14.039
LOG GHG intensity	5.193	5.104
LOG Scope 1 emission intensity	2.533	2.413
LOG Scope 2 emission intensity	2.672	2.531
LOG Scope 3 emission intensity	4.614	4.523
Environmental pillar score	54.211	60.543
RET (%)	0.935	0.720
IO (%)	70.276	68.742
$LOGSIZE$	23.548	23.766
B/M	0.774	0.796
$LEVERAGE$	0.270	0.289
MOM (%)	0.639	0.800
$INVEST/A$	-0.034	-0.032
HHI	2.629	2.834
$LOGPPE$	22.497	22.933
ROE	0.126	0.074
$VOLAT$	0.072	0.083
$GParachute$	0.544	0.494
$ENUSEPC$	4787.164	4697.580
$REOUTPUT$ (%)	19.606	21.761
CDA	57.394	59.805
$CPCOVERAGE$ (%)	30.149	33.368

Table 3
Predictors of declarations of net zero commitment

The sample period is from 2016 to 2022. The dependent variable is the declaration of NZC. All variables have been defined in Table 1. Columns (1), (3), (5) and (7) reflect the adoption of Probit models, and Columns (2), (4), (6) and (8) reflect the adoption of Logit models. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Variables: D^{NZ}	(1) Probit	(2) Logit	(3) Probit	(4) Logit	(5) Probit	(6) Logit	(7) Probit	(8) Logit
LOG GHG	-0.06***	-0.11***			-0.01**	-0.02*		
	(0.01)	(0.02)			(0.01)	(0.01)		
LOG GHG intensity			-0.14***	-0.24***			0.01*	0.03**
			(0.02)	(0.03)			(0.01)	(0.01)
LOG SIZE	0.26***	0.49***	0.23***	0.45***	0.11***	0.19***	0.12***	0.20***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
B/M	0.08***	0.14***	0.08***	0.14***	-0.04***	-0.08***	-0.03**	-0.06***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
LEVERAGE	-0.13***	-0.17*	-0.13**	-0.16*	-0.07*	-0.10	-0.07*	-0.10
	(0.05)	(0.09)	(0.05)	(0.09)	(0.04)	(0.07)	(0.04)	(0.07)
INVEST/A	0.04***	0.07***	0.03***	0.07***	0.01***	0.03***	0.01***	0.03***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
HHI	-0.01***	-0.03**	-0.01***	-0.02**	0.01*	0.01	0.00	0.00
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)
LOG PPE	0.06***	0.10***	0.04***	0.05**	0.11***	0.21***	0.09***	0.17***
	(0.01)	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
ROE	-0.00**	-0.01**	-0.00***	-0.01**	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
IO	0.00***	0.00***	0.00***	0.00***	0.00*	0.00**	0.00*	0.00**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
MOM	-0.01***	-0.02***	-0.01***	-0.02***	-0.01***	-0.02***	-0.01***	-0.02***

	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)
VOLAT	-0.01***	-0.02***	-0.01***	-0.02***	-0.01***	-0.01***	-0.01***	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Year/month-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes	No	No	No	No
Observations	69897	69897	69897	69897	69897	69897	69897	69897

Table 4
Carbon emissions and stock returns

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are GHG emissions levels in Column (1) and GHG intensity levels in Column (2). All variables have been defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: *RET*	(1) *Emissions = GHG level*	(2) *Emissions = GHG intensity*
Emissions	-0.22***	0.14**
	(0.05)	(0.07)
LOG SIZE	0.93***	0.88***
	(0.06)	(0.05)
B/M	-0.15***	-0.17***
	(0.05)	(0.05)
LEVERAGE	-0.09	-0.04
	(0.20)	(0.20)
MOM	-0.18***	-0.18***
	(0.01)	(0.01)
INVEST/A	-0.02	-0.03*
	(0.01)	(0.01)
HHI	0.01	0.01
	(0.02)	(0.02)
LOG PPE	-0.47***	-0.61***
	(0.06)	(0.05)
ROE	0.01**	0.01**
	(0.01)	(0.01)
VOLAT	0.20***	0.20***
	(0.01)	(0.01)
Year/month-fixed effects	Yes	Yes
Country-fixed effects	Yes	Yes
Industry-fixed effects	Yes	Yes
Observations	72276	72276
R-squared	0.258	0.258

Table 5
Carbon emissions and stock returns by region

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels. Firms are classified by their locations. Column (1) corresponds to firms in North America; Column (2) corresponds to firms in Europe; and Column (3) corresponds to firms in all other regions. All variables are defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: *RET*	(1) North America	(2) Europe	(3) Others
LOG GHG intensity	0.20*	0.28*	-0.03

	(0.12)	(0.17)	(0.15)
Controls	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes
Observations	31179	22573	18522
R-squared	0.319	0.312	0.192

Table 6
Carbon emissions, net zero commitment and stock returns

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels and D^{NZ}, a dummy variable equal to one if a firm has declared NZC and 0 otherwise. All variables are defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: RET	(1)
LOG GHG intensity	0.13*
	(0.07)
D^{NZ}	-0.07
	(0.27)
LOG GHG intensity × D^{NZ}	0.02
	(0.05)
Controls	Yes
Year/month-fixed effects	Yes
Country-fixed effects	Yes
Industry-fixed effects	Yes
Observations	72276
R-squared	0.258

Table 7
Carbon emissions, net zero commitment and stock returns: Transition capacity

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels and D^{NZ}, a dummy variable equal to one if a firm has declared NZC and 0 otherwise. Column (1) corresponds to firms in countries with a lower-than-median energy use per capita in the full sample; Column (2) corresponds to firms in countries with a higher-than-median energy use per capita in the full sample. Column (3) corresponds to firms in countries with a lower-than-median share of renewable electricity output in the full sample; Column (4) corresponds to firms in countries with a higher-than-median share of renewable electricity output in the full sample. All variables have been defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: RET	(1) Energy use per capita < Median	(2) Energy use per capita > Median	(3) Share of renewable electricity output > Median	(4) Share of renewable electricity output < Median
LOG GHG intensity	0.15	0.13	0.04	0.23**
	(0.12)	(0.10)	(0.12)	(0.11)
D^{NZ}	0.63	-0.59	0.65	-0.78**
	(0.43)	(0.38)	(0.43)	(0.39)
LOG GHG intensity × D^{NZ}	-0.12	0.13**	-0.13*	0.17**
	(0.08)	(0.07)	(0.08)	(0.07)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Observations	30707	39288	30784	36907

R-squared	0.240	0.297	0.228	0.308

Table 8
Carbon emissions, net zero commitment and stock returns: Transition urgency

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels and D^{NZ}, a dummy variable equal to one if a firm has declared NZC and equal to 0 otherwise. Column (1) corresponds to firms in countries with a higher-than-median score of policy-driven trend in CO_2 emissions intensity in the full sample; Column (2) corresponds to firms in countries with a lower-than-median score of policy-driven trend in CO_2 emissions intensity in the full sample; Column (3) corresponds to firms in countries with a higher-than-median share of GHG emissions covered by a carbon price in the full sample; Column (4) corresponds to firms in countries with a lower-than-median share of GHG emissions covered by a carbon price in the full sample. All variables have been defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: RET	(1) Score of CO2 per GDP trend > Median	(2) Score of CO2 per GDP trend < Median	(3) Share of GHG emissions covered by a carbon price > Median	(4) Share of GHG emissions covered by a carbon price < Median
LOG GHG intensity	0.24**	0.13	0.05	0.23**
	(0.12)	(0.10)	(0.13)	(0.10)
D^{NZ}	0.98**	-0.54	0.62	-0.75**
	(0.43)	(0.37)	(0.42)	(0.37)
LOG GHG intensity × D^{NZ}	-0.18***	0.12*	-0.11	0.15**
	(0.08)	(0.07)	(0.08)	(0.06)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Observations	29183	42924	31190	40056
R-squared	0.257	0.277	0.244	0.285

Table 9
Carbon emissions, net zero commitment and stock returns: Discount rates

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels and D^{NZ}, a dummy variable equals one if firm has declared NZC and 0 otherwise. Column (1) corresponds to observations with environmental pillar scores above the median in the full sample; Column (2) corresponds to observations with environmental pillar scores below the median in the full sample; Column (3) corresponds to observations without golden parachute rules; Column (4) corresponds to observations with golden parachute rules. All variables are defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: RET	(1) E score > Median	(2) E score < Median	(3) Without golden parachute	(4) With golden parachute
LOG GHG intensity	0.45***	-0.10	-0.06	0.18
	(0.12)	(0.10)	(0.14)	(0.12)
D^{NZ}	0.75*	-0.75*	0.47	-0.76*
	(0.39)	(0.43)	(0.46)	(0.45)
LOG GHG intensity × D^{NZ}	-0.14*	0.15**	-0.09	0.16**
	(0.07)	(0.07)	(0.08)	(0.08)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes

Observations	34292	35921	24798	30064
R-squared	0.271	0.265	0.276	0.319

Table 10
Carbon emissions, net zero commitment, and institutional ownership

The sample period is from 2016 to 2022. The dependent variable is IO. The main independent variables are GHG emissions, GHG emission intensity and D^{NZ}, a dummy variable equal to one if a firm has declared NZC and 0 otherwise. All variables are defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: IO	(1) *Emissions = GHG level*	(2) *Emissions = GHG level*	(3) *Emissions = GHG intensity*	(4) *Emissions = GHG intensity*
Emissions	-0.05	0.12	-1.51***	-1.36***
	(0.10)	(0.10)	(0.14)	(0.14)
D^{NZ}		7.20***		2.76***
		(1.04)		(0.54)
Emissions × D^{NZ}		-0.42***		-0.35***
		(0.07)		(0.10)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Observations	68946	68946	68946	68946
R-squared	0.663	0.663	0.663	0.663

Table 11
Carbon emissions, net zero commitment, and institutional ownership: excluding salient high-emitting industries

The sample excludes companies in the Energy, Transportation, and Utilities. The sample period is from 2016 to 2022. The dependent variable is IO. The main independent variables are GHG emissions, GHG emission intensity and D^{NZ}, a dummy variable equal to one if a firm has declared NZC and 0 otherwise. All variables have been defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: IO	(1) *Emissions = GHG level*	(2) *Emissions = GHG level*	(3) *Emissions = GHG intensity*	(4) *Emissions = GHG intensity*
Emissions	-0.80***	-0.59***	-1.51***	-1.35***
	(0.13)	(0.13)	(0.19)	(0.19)
D^{NZ}		8.27***		2.39***
		(1.16)		(0.62)
Emissions × D^{NZ}		-0.52***		-0.34***
		(0.08)		(0.12)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Observations	57170	57170	57170	57170
R-squared	0.679	0.679	0.679	0.679

Table 12
Carbon emissions, net zero commitment and stock return

The sample period is from 2016 to 2022. The dependent variable is RET. The main independent variables are carbon intensity levels and D^{NZ}, a dummy variable equal one if a firm has declared NZC and 0 otherwise. Column

(1) corresponds to observations with first quartile institutional ownership; Column (2) corresponds to observations with second quartile institutional ownership; Column (3) corresponds to observations with third quartile institutional ownership; Column (4) corresponds to observations with fourth quartile institutional ownership. All variables are defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: RET	(1) IO:1st quartile	(2) IO:2nd quartile	(3) IO:3rd quartile	(4) IO:4th quartile
$LOG\ GHG\ intensity$	0.12	0.12	0.20	0.33*
	(0.19)	(0.20)	(0.14)	(0.18)
D^{NZ}	0.60	0.37	-0.96*	-1.13**
	(0.64)	(0.63)	(0.57)	(0.57)
$LOG\ GHG\ intensity \times D^{NZ}$	-0.13	-0.02	0.18*	0.23**
	(0.11)	(0.11)	(0.10)	(0.11)
Controls	Yes	Yes	Yes	Yes
Year/month-fixed effects	Yes	Yes	Yes	Yes
Country-fixed effects	Yes	Yes	Yes	Yes
Industry-fixed effects	Yes	Yes	Yes	Yes
Observations	14687	15220	18508	20526
R-squared	0.214	0.262	0.264	0.342

Appendix A1:

We deploy optimal control theory to solve the maximization problem (P) in Section 3. For each $t \in [0,1]$, the Hamiltonian equation is defined by

$$H\big(t, x(t), u(t), \lambda(t)\big) = e^{-rt}\left(g(t) - \beta x(t) - \frac{u(t)^2}{2\kappa}\right) - \lambda(t)u(t),$$

where $\lambda(t)$ is a continuous function adjoint of constraint $\dot{x}(t) = -u(t)$. Note that the Hamiltonian is concave at $\big(x(t), u(t)\big)$. By Theorems 9.10.2 and 9.10.3 in Sydsaeter et al. (2008), a pair of functions $\big(x^*(t), u^*(t)\big)$ are a solution to (P) if and only if they satisfy the relevant constraints in the problem and the following conditions: for all $t \in [0,1]$,

(1) $u(t) = u^*(t)$ maximizes $H\big(t, x^*(t), u(t), \lambda(t)\big)$ for $u(t) \geq 0$;

(2) $\dot{\lambda}(t) = -\,\partial H\big(t, x^*(t), u^*(t), \lambda(t)\big)/\partial x(t)$ whenever $u^*(t)$ is continuous.

Now, we examine the implications of each of the two conditions. For condition (1), note that

$$\frac{\partial H\big(t, x^*(t), u(t), \lambda(t)\big)}{\partial u(t)} = -e^{-rt}\frac{u(t)}{\kappa} - \lambda(t)$$

If $\lambda(t) \geq 0$, then $H\big(t, x^*(t), u(t), \lambda(t)\big)$ is decreasing in $u(t)$; thus, $u^*(t) = 0$. If $\lambda(t) < 0$, however, then strict concavity of $H\big(t, x^*(t), u(t), \lambda(t)\big)$ in $u(t)$ implies that $u^*(t)$ is pinned down by the first-order condition. Together, these imply

(E1)
$$u^*(t) = \begin{cases} 0 & \text{if } \lambda(t) \geq 0 \\ -\kappa e^{rt}\lambda(t) & \text{if } \lambda(t) < 0 \end{cases}$$

Second, we study condition (2). Note that

$$\frac{\partial H\big(t, x^*(t), u^*(t), \lambda(t)\big)}{\partial x(t)} = -\beta e^{-rt}$$

This means $\dot{\lambda}(t) = \beta e^{-rt}$. Simple integration implies that, for some constant A_1,

(E2)
$$\lambda(t) = -\frac{\beta}{r}e^{-rt} + A_1.$$

From (E2), note that $\dot{\lambda}(t) > 0$. Applying this to (E1), we can divide the analysis into 3 cases: (a) $\lambda(1) \leq 0$; (b) $\lambda(0) < 0 < \lambda(1)$; and (c) $\lambda(0) \geq 0$. Case (c) can be ruled out directly, as this would imply $u^*(t) = 0$ for all $t \in [0,1]$ and thus $x^*(1) = x_0$, a contradiction. Next, we study cases (a) and (b).

Case (a): From (E1) and (E2), $u^*(t) = \frac{\beta\kappa}{r} - \kappa e^{rt}A_1$ for all $t \in [0,1]$. Applying this to the constraint $u^*(t) = -\dot{x}^*(t)$ yields $x^*(t) = -\frac{\beta\kappa}{r}t + \frac{\kappa}{r}e^{rt}A_1 + A_2$ for some constant A_2. However, the initial and terminal conditions pin down two simultaneous equations:

$$\begin{cases} x^*(0) = \dfrac{\kappa}{r}A_1 + A_2 = x_0 \\ x^*(1) = -\dfrac{\beta\kappa}{r} + \dfrac{\kappa}{r}e^r A_1 + A_2 = (1-\phi)x_0 \end{cases}$$

Solving the above system yields $A_1 = \frac{\beta\kappa + r(x_1 - x_0)}{\kappa(e^r - 1)}$ and $A_2 = -\frac{\beta\kappa + r(x_1 - x_0 e^r)}{r(e^r - 1)}$. Plugging the constants back into $x^*(t)$ expression above yields

(E3)
$$x^*(t) = \begin{cases} x_0 - \dfrac{\beta\kappa}{r}t - \left(\dfrac{e^{rt} - 1}{e^r - 1}\right)\left(\phi x_0 - \dfrac{\beta\kappa}{r}\right) & \text{if } t < 1 \\ x_1 & \text{if } t \geq 1 \end{cases}$$
$$u^*(t) = \begin{cases} \dfrac{\beta\kappa}{r} + \dfrac{r\phi x_0 - \beta\kappa}{e^r - 1}e^{rt} & \text{if } t < 1 \\ 0 & \text{if } t \geq 1 \end{cases}$$

(E2) implies $\lambda(t) = \frac{\beta}{r}\frac{e^{-r}}{1 - e^{-r}}(r + e^{-rt} - e^{r(1-t)} - \frac{r^2\phi x_0}{\beta\kappa})$. However, the solution is consistent with $\lambda(1) \leq 0$ if and only if $r + e^{-r} \leq 1 + \frac{r^2\phi x_0}{\beta\kappa}$, as desired.

Case (b): According to the intermediate value theorem, there exists a unique $\tau \in (0,1)$ such that $\lambda(\tau) = 0$. Fix that τ. By (E1), $u^*(t) = 0$ and $x^*(\tau) = x_1$ for $t \in [\tau, 1]$. Below, we derive the solution for the range $t \in [0, \tau)$. From (E1) and (E2), we have $u^*(t) = \frac{\beta\kappa}{r} - \kappa e^{rt}A_1$. Applying this to the constraint $u^*(t) = -\dot{x}^*(t)$ yields $x^*(t) = -\frac{\beta\kappa}{r}t + \frac{\kappa}{r}e^{rt}A_1 + A_2$ for some constant A_2. The initial and terminal conditions pin down two simultaneous equations:

$$\begin{cases} x^*(0) = \dfrac{\kappa}{r}A_1 + A_2 = x_0 \\ x^*(\tau) = -\dfrac{\beta\kappa}{r}\tau + \dfrac{\kappa}{r}e^{r\tau}A_1 + A_2 = (1-\phi)x_0 \end{cases}$$

Solving the above system yields $A_1 = \frac{\beta\kappa\tau + r(x_1 - x_0)}{\kappa(e^{r\tau} - 1)}$ and $A_2 = -\frac{\beta\kappa\tau + r(x_1 - x_0 e^{r\tau})}{r(e^{r\tau} - 1)}$. Plugging the constants back into the $x^*(t)$ expression above yields

(E4)
$$x^*(t) = \begin{cases} x_0 - \dfrac{\beta\kappa}{r}t - \left(\dfrac{e^{rt} - 1}{e^{r\tau} - 1}\right)\left(\phi x_0 - \dfrac{\beta\kappa}{r}\tau\right) & \text{if } t < \tau \\ x_1 & \text{if } t \geq \tau \end{cases}$$
$$u^*(t) = \begin{cases} \dfrac{\beta\kappa}{r} + \dfrac{r\phi x_0 - \beta\kappa\tau}{e^{r\tau} - 1}e^{rt} & \text{if } t < \tau \\ 0 & \text{if } t \geq \tau \end{cases}$$

(E2) implies $\lambda(t) = -\frac{\beta}{r}e^{-rt} + \frac{\beta\kappa\tau + r(x_1 - x_0)}{\kappa(e^{r\tau} - 1)}$. Yet the condition $\lambda(\tau) = 0$ is equivalent to

(E5)
$$r\tau + e^{-r\tau} = 1 + \frac{r^2\phi x_0}{\beta\kappa}$$

As $r\tau + e^{-r\tau}$ increases in τ, the solution is consistent with the constraint $\tau < 1$ if and only if $r + e^{-r} > 1 + \frac{r^2\phi x_0}{\beta\kappa}$, as desired. Finally, note that (E5) is equivalent to $\tau = \frac{1}{r}F\left(\frac{r^2\phi x_0}{\beta\kappa}\right)$. ■

Appendix A2:

The V_a expression in the proposition can be derived by plugging the solutions in (E3) into (P):

$$\int_0^{\infty} e^{-rt}\left(g(t) - \beta x^*(t) - \frac{1}{2\kappa}u^*(t)^2\right)dt = V_a$$

Statement (i):

$$\frac{\partial V_a}{\partial x_0} = \frac{\beta}{r}\left(\phi\frac{r - \frac{r^2\phi x_0}{\beta\kappa}}{e^r - 1} - 1\right) < \frac{\beta}{r}\left(\phi\frac{1 - e^{-r}}{e^r - 1} - 1\right) < 0$$

The first inequality holds by rearranging the precondition $r + e^{-r} < 1 + \frac{r^2\phi x_0}{\beta\kappa}$, and the second inequality holds because $\phi \in (0,1)$ and $e^r + e^{-r} > 2$ for $r > 0$.

Statement (ii):

$$\frac{\partial V_a}{\partial \phi} = \frac{\beta x_0}{e^r - 1}\left(1 - \frac{r\phi x_0}{\beta\kappa}\right)$$

The characterization is self-evident.

Statement (iii):

$$\frac{\partial^2 V_a}{\partial\phi\partial x_0} = \frac{2\beta x_0}{e^r - 1}\left(\frac{1}{2} - \frac{r\phi x_0}{\beta\kappa}\right)$$

The characterization is self-evident. ■

Appendix A3:

With $\tau = \frac{1}{r}F\left(\frac{r^2\phi x_0}{\beta\kappa}\right)$, the V_b expression in the proposition can be derived by plugging the solutions in (E4) into (P):

$$\int_0^{\infty} e^{-rt}\left(g(t) - \beta x^*(t) - \frac{1}{2\kappa}u^*(t)^2\right)dt = V_b$$

For simplicity, let $\theta \equiv \frac{r^2\phi x_0}{\beta\kappa}$. As the variable τ involves the principal branch of the Lambert W function W_0, we first point out that $W_0\left(-e^{-1-\theta}\right) \in (-1,0)$. The following partial derivatives stem from applying (E5) and some key properties of W_0; a detailed derivation is omitted.

Statement (i):

$$\frac{\partial V_b}{\partial x_0} = -\frac{\beta}{r}\left(1 + \phi W_0\left(-e^{-1-\theta}\right)\right) < 0$$

This inequality holds because $\phi \in (0,1)$.

Statement (ii):

$$\frac{\partial V_b}{\partial \phi} = -\frac{\beta}{r} x_0 W_0\left(-e^{-1-\theta}\right) > 0$$

The characterization is self-evident.

Statement (iii):

$$\frac{\partial^2 V_b}{\partial \phi \partial x_0} = \frac{\beta}{r} \frac{-W_0\left(-e^{-1-\theta}\right)}{1 + W_0\left(-e^{-1-\theta}\right)}\left(1 + W_0\left(-e^{-1-\theta}\right) - \theta\right)$$

Hence, the sign of the cross partial derivative is that of $G(\theta) \coloneqq 1 + W_0\left(-e^{-1-\theta}\right) - \theta$. Note that $\lim_{\theta \to 0^+} G(\theta) = 0$ and $G''(\theta) = \frac{W_0\left(-e^{-1-\theta}\right)}{\left(1+W_0\left(-e^{-1-\theta}\right)\right)^3} < 0$. Therefore, if there exists $\theta^* > 0$ such that $G(\theta^*) = 0$, then the solution is also unique. It can be derived that $\theta^* = 1 + \frac{1}{2} W_0(-2e^{-2})$. However, the concavity of G implies that $G(\theta) < 0$ if and only if $\theta > \theta^*$. ■

Appendix B:

This appendix evaluates the carbon risk premium by re-estimating Equation (1) over the sample period from 2005 to 2022. Extending the sample allows for a better comparison with the results of Bolton and Kacperczyk (2023), which covers 2005 to 2018.

The estimation results are presented in Table B1. Columns (1) and (2) report the estimates using the natural log scale of total GHG emissions and GHG emission intensity, respectively, as the key independent variables. In Column (1), we find a negative relationship between GHG levels and stock returns, indicating an absence of carbon risk premium in GHG levels. However, in Column (2), we find a positive and statistically significant relationship between GHG emission intensities and stock returns. Specifically, a 1% increase in the level of emission intensity corresponds to a 14-bps increase in monthly stock returns, or a 1.7% increase in annualized returns. These consistent signs of the estimated coefficients with our results suggest that even when extending the sample period to 2005-2022, investors' demand for compensation differs between large firms and all firms.

Table B1
Carbon emissions and stock returns

The sample period is from 2005 to 2022. The dependent variable is *RET*. The main independent variables are GHG emissions levels in Column (1) and GHG intensity levels in Column (2). All variables have been defined in Table 1. Standard errors are presented in parentheses. All regressions include year/month-fixed effects, country-fixed effects, and industry fixed-effects. *** 1% significance; ** 5% significance; * 10% significance.

Dependent Variables: *RET*	(1) *Emissions = GHG level*	(2) *Emissions = GHG intensity*
Emissions	-0.29***	0.14***
	(0.03)	(0.04)
Controls	Yes	Yes
Year/month-fixed effects	Yes	Yes
Country-fixed effects	Yes	Yes
Industry-fixed effects	Yes	Yes
Observations	187796	187796
R-squared	0.236	0.236